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NAVAL POSTGRADUATE SCHOOL
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INITIAL RESEARCH ON AN INVENTORY
CONTROL PROCESS FOR
LOW ATTRITION REPAIRABLE ITEMS

by

Mark D. Dexter

December 1989

Thesis Advisor Thomas P. Moore

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This thesis presents the initial research findings for a proposed wholesale level inventory control process for low attrition Depot Level Repairables (DLRs) and is the start of a continuing research effort directed by Professor Thomas P. Moore of the Naval Postgraduate School. The main objectives of this study were to determine if the data required for the proposed model were available in the existing data bases at the Navy Ships Parts Control Center (SPCC) or available from other sources, collect the data for a small number of DLRs, and make recommendations for future study. The major conclusion was that implementation of the proposed model would require major changes in SPCC's current repair induction policies and procedures.

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Initial Research on an Inventory Control Process For Low Attrition Repairable Items

by

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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December 1989

This thesis presents the initial research findings for a proposed wholesale level inventory control process for low attrition Depot Level Repairables (DLRs) and is the start of a continuing research effort directed by Professor Thomas P. Moore of the Naval Postgraduate School. The main objectives of this study were to determine if the data required for the proposed model were available in the existing data bases at the Navy Ships Parts Control Center (SPCC) or available from other sources, collect the data for a small number of DLRs, and make recommendations for future study. The major conclusion was that implementation of the proposed model would require major changes in SPCC's current repair induction policies and procedures.

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I. INTRODUCTION

A. BACKGROUND

This thesis presents the initial research findings for a proposed wholesale level Depot Level Repairable (DLR) inventory model and is the start of a continuing research effort directed by Professor Thomas P. Moore of the Naval Postgraduate School. More specifically, the proposed model is for low attrition DLRs. For this study, a low attrition DLR is one that is lost, stolen, or beyond economical repair less than one percent of the time. The accuracy of the proposed model for various levels of attrition has yet to be determined, but, as the reader will see in Chapter III, the proposed model seems best suited to the low attrition case. Also, this thesis focuses on DLRs managed by the Navy Ships Parts Control Center (SPCC) in Mechanicsburg, PA.

The low attrition DLR model was proposed by Professor Moore in a paper presented at the CORS TIMS ORSA Joint National Meeting in May 1989. The model uses optimization, queueing theory, and the Wilson-Harris Economic Order Quantity (EOQ) formula to determine the population of owned material (installed and spares), when to buy (attrition reorder point), and how much to buy (attrition order quantity).

The Navy presently uses independent models to determine the inventory levels for each echelon of supply. That is, the Navy has three levels of supply--wholesale, retail intermediate, and retail consumer--and at each of these levels, independent mathematical models are used to compute reorder points and reorder quantities. The levels of inventory are defined as follows: [Ref. 1: p. 1-13]

- Wholesale inventory -- Material over which the inventory manager has visibility and control worldwide.
- Retail Intermediate Inventory -- A level of inventory between the consumer and wholesale levels used to support a geographical area.
- Retail Consumer Inventory -- Inventory held strictly for a specific unit or activity for its own use.

Wholesale inventories are positioned at stock points, such as Naval Supply Centers (NSC), by the item manager. Item managers for Navy material are at one of two Navy Inventory Control Points (ICPs): Navy Ships Parts Control Center (SPCC) or Navy Aviation Supply Office (ASO). The wholesale inventory levels are computed based on

worldwide demand and are set by SPCC or ASO. Material is also purchased by SPCC or ASO and pushed to the stock points by the ICP.

Retail intermediate inventories are also positioned at stock points, but, in addition, are located on ships such as repair ships (ARs), tenders (AD or AS), and combat logistics force ships (AFS). Unlike the wholesale level, requirements at the retail intermediate level are based on demands experienced in a geographical area. For example, NSC Charleston uses the demands for material received from ships in the Charleston area to determine the inventory levels it carries. So, each activity holding retail intermediate stocks computes its own inventory levels based on geographical demand and each activity purchases or pulls its own retail stocks. It should be noted that for NSCs having both retail and wholesale stocks of the same item, the NSC doesn't really maintain separate retail stocks, but pulls from the wholesale level as demands occur. In this situation, the wholesale level, in effect, provides support directly to the customer.

Retail consumer inventories are positioned on ships, with aircraft squadrons, and at shore commands. These consumer level inventories are designed to support the individual activity's operations for a specified period of time (i.e., 90 days for ships). This level of inventory is often called on board repair parts or storeroom items.

By the year 2005, the Navy plans to eliminate the independent inventory models and implement a multi-echelon optimization model for repair parts used in weapon systems [Ref. 2: p. 7]. The multi-echelon inventory model will use weapon system operational availability (A_o) as the primary measure of effectiveness (MOE), where A_o is defined as the probability that a weapon system is capable of being placed into operation upon demand for a specified mission [Ref. 2: p. 2].

The implementation of the multi-echelon inventory model will be done in three phases. Part of the first phase is the study of improved inventory models [Ref. 2: p. 5]. Hopefully, this thesis will eventually lead to an improved DLR inventory model.

Until the implementation of a system wide, multi-echelon model in 2005, independent inventory models will be used at each of the three levels of supply with Supply Material Availability (SMA) being the primary, interim MOE used to judge the performance of the supply system [Ref. 2: p. D-9]. However, it should be noted that Mean Supply Response Time (MSRT) is being used as a MOE for some inventory systems and that MSRT will, in the author's opinion, eventually replace SMA as the primary MOE.

As previously stated, the proposed model is for the wholesale inventory level and will initially use SMA as the MOE. Since the current wholesale DLR inventory model uses SMA as the MOE, the proposed model's MOE should be SMA so that the

performance of the two models is measured and judged on the same standard. Future studies could, however, measure the performance of both models using MSRT, A_0 , or any other MOE.

B. OBJECTIVES

The objectives of this study are:

- To provide a clear description of the current SPCC DLR levels computation model and the proposed levels computation model.
- To determine if the data for the random variables in the proposed model are available in the SPCC Weapons System File (WSF) and Uniform Inventory Control Program (UICP) data bases.
- To collect available data from the WSF and UICP data bases for a small sample of DLRs.
- For data not available in the WSF or UICP data bases, examine ways to collect the data and recommend data collection procedures.
- To assist in the future study of the proposed inventory model by programming the current SPCC DLR inventory model using FORTRAN level 77.
- Evaluate the validity of the proposed model's assumptions.

C. LIMITATIONS

The limitations of this study are:

- This thesis is restricted to basic research; therefore, the study only addresses data collection possibilities and developing an emulation of the current levels setting program. Professor Moore's ultimate goal is to compare the proposed model's performance against the performance of the current model. To reach this performance comparison goal, further research and programming will be required.
- Actual data is only collected for 12 items. Determining if the data required for the proposed model is readily available and, if not readily available, finding ways to collect it are the primary objectives of this thesis. A larger sample was not necessary to meet these objectives and would have hampered the effort. Future studies will, of course, have to expand the number of items examined.
- Any implemented inventory model must contain a budget constraint somewhere in the process. However, because of the limited number of items in the sample, the formulation of a budget constraint is not considered in this thesis. As future studies expand the number of items examined, a budget constraint must be added to the proposed model.
- SPCC's forecasts are used as input variables for both models. To get a valid comparison of the current and proposed models, the proposed model should use SPCC's forecasts. If different forecasts were developed for the proposed model, attributing the proposed model's success or failure to the model alone would be impossible since the forecasts could strongly influence the model's success or failure.

D. METHODOLOGY

Figure 1 provides an overview for the entire study as envisioned by the author and Professor Moore. Referring to Figure 1, this thesis only covers collecting the data and forecasts from SPCC, collecting repair rates and repair channel information from the Designated Overhaul Points (DOPs), collecting failure rate data from various sources, and programming the current SPCC levels setting model.

Programming the proposed levels setting model, collecting Transaction History File (THF) data, developing a THF data filtering program, preparing a simulation, and evaluating the simulation results will require further work by Professor Moore and several thesis students.

As Figure 1 shows, SPCC data and forecasts will be used as input to an emulation program that replicates part of the SPCC levels program. The SPCC levels program uses individual observations, such as demand, to generate forecasts and then computes the procurement quantity, procurement reorder level, repair quantity, and repair level. The emulation program developed in this thesis uses the forecasts generated by SPCC's levels program as input and generates the procurement and repair levels.

The emulation program was developed to increase the understanding of the current levels model, to show the quantities generated in the intermediate steps of the SPCC model if needed for future analysis, and to provide flexibility in answering "what if" questions in future studies. It should be noted that actual results from SPCC's levels program should always be collected to ensure that the emulation program is producing accurate results.

Figure 1 also shows that input to the proposed levels setting program consists of data from the DOPs, failure rate data, and SPCC data. The levels setting program then calculates a total ownership quantity and generates a procurement reorder level quantity and a procurement quantity. The proposed model assumes that either the repair quantity is one and repairs are done as DLRs fail, or that repairs are accomplished when the number of failed DLRs reaches a set level (i.e., batch inductions to the repair process).

Referring to Figure 1 again, SPCC's Transaction History File (THF) contains two years of inventory transaction data for each DLR. This transaction data for each DLR will be processed by a transaction filtering program. This filtering program will eliminate unnecessary transactions and retain records for transactions such as demands, surveys, carcass returns, repair inductions, and repair completions. In addition, the transaction filtering program can be used to identify DLRs that haven't had any repair inductions in the past two years.

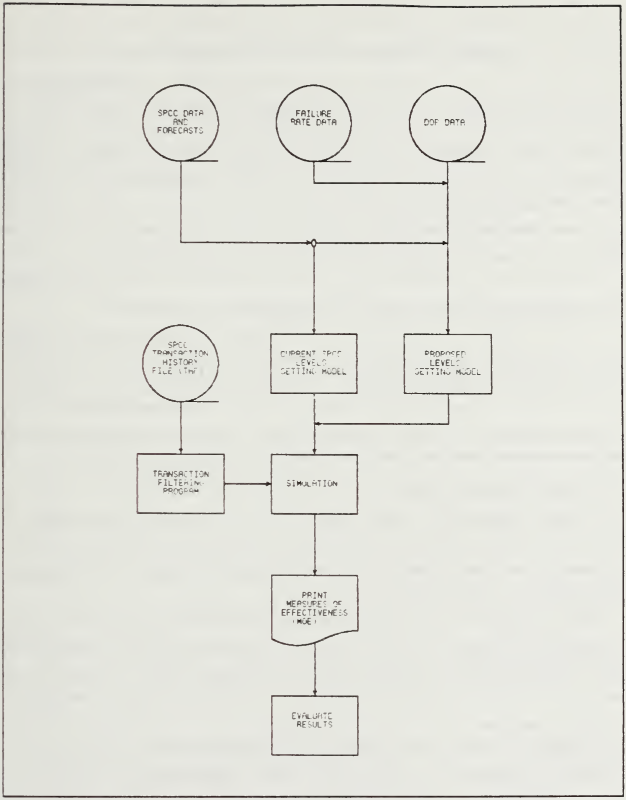

Figure 1. Overview for the Entire Study.

The outputs from the current levels setting program, the proposed levels setting model program, and the transaction filtering program will then be used as inputs to a simulation program. The simulation program will use asset and requirements information from the UICP files to establish an initial inventory position. The output from the transaction filtering program will then be processed chronologically so that the inventory position is adjusted with each transaction processed through the simulation. For each inventory model, the simulation will track the inventory position, number of orders, number of stock outs, costs, etc. The simulation will then calculate SMA,[1] budget, and other pertinent measures of effectiveness.

Finally, the MOEs generated by the simulation will be evaluated to determine if the proposed model is significantly more effective than the current model.

As stated earlier, this thesis is only the start of a long effort to accomplish the entire study as presented in Figure 1 and described in the preceding paragraphs.

For this thesis, WSF and UICP data and forecasts were collected primarily from SPCC's Repairables Support Department (code 0351) and SPCC's Systems Services Division (code 042). Additionally, interviews were conducted with people from commercial and Navy repair depots, other SPCC codes, the Navy Fleet Material Support Office (FMSO) and the Naval Warfare Assessment Center, Corona, CA to gather data for the proposed model and evaluate the validity of the proposed model's assumptions.

E. THESIS ORGANIZATION

Chapter II describes the current SPCC DLR levels setting model and Chapter III describes the proposed low attrition DLR levels setting model. These chapters provide the reader with an understanding of the theories behind the models and the assumptions upon which the models are based.

Chapter IV describes the data collection methods, difficulties in selecting the sample National Stock Numbers (NSNs), difficulties in collecting data for the current SPCC model, and difficulties in collecting data for the proposed model. The chapter also identifies the variables requiring data collection, data collection sources, and data collection assumptions.

Chapter V provides a brief analysis of the proposed model's assumptions and Chapter VI summarizes the major issues and offers recommendations for future study.

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1 As already noted, MOE's such as MSRT or A_0 could be substituted for SMA. The final MOEs will be determined in future studies.

II. CURRENT SPCC LEVELS SETTING MODEL

A. BACKGROUND

SPCC operates, and the Navy Fleet Material Support Office (FMSO) maintains, numerous computer programs and files to support the wholesale inventory system. These computer programs and files are collectively called the Uniform Inventory Control Program (UICP). UICP programs can be generally classified as data gathering programs or requirements determination programs. This chapter deals with one of the UICP requirements determination programs: Cyclic Levels and Forecasting (FMSO program D01).

The Cyclic Levels and Forecasting Program, commonly called Levels, performs the following functions: [Ref. 1: p. 3-27]

- Produces forecasts, using simple exponential smoothing, for variables such as demand, carcass returns, lead times, repair turnaround times, and repair survival rates. These new forecast values are added to the UICP files.

- Changes the mark code of the item if the demand forecast or unit cost has changed significantly. Every wholesale inventory item is assigned a mark code based on the item's forecasted quarterly demand and unit cost. There are five mark codes that range from 0 to IV. Items having a mark code of 0 are slow movers, while items having mark codes of I or III are medium movers or medium demand items, and items having mark codes of II or IV are fast movers or high demand items. [Ref. 1: p. 3-10] Classifying items into mark code categories is important because the UICP levels program uses the mark code to determine the lead time demand distribution that will be used for levels computation. Table 1 shows a cross reference between mark codes and lead time demand distributions used in the levels program.

  The Value of Quarterly Demand (VQD) listed in Table 1 is simply the quarterly demand multiplied by the item's unit cost. The current break point between low VQD and high VQD is $175.00. The quarterly demand break points are 0.25 or less for low demand, between 0.25 and 5 for medium demand, and 5 or above for high demand. [Ref. 3]

- Assigns and changes shipper and receiver designations. Shipper activities are those that don't have enough demand to warrant maintaining wholesale level operating stocks or don't have the capacity to handle the items. Receivers are those activities that have enough demand to justify stocking an item and have the capacity to do so.

- Computes the wholesale level order quantity, reorder point, repair quantity, repair level, receiver reorder points, and receiver safety stocks.

Table 1. CROSS REFERENCE BETWEEN MARK CODES AND DISTRIBUTIONS USED IN THE UICP LEVELS PROGRAM

		Distribution Used For Levels Computation	
Mark Code	Mark Code Meaning	Consumables	Repairables
0	Low Quarterly Demand	Poisson	Negative Binomial
I	Medium Quarterly Demand and Low Value of Quarterly Demand (VQD)	Negative Binomial	Negative Binomial
II	High Quarterly Demand and Low VQD	Normal	Normal
III	Medium Quarterly Demand and High VQD	Negative Binomial	Negative Binomial
IV	High Quarterly Demand and High VQD	Normal	Normal

This thesis deals strictly with part of the last levels function described in the preceding paragraph: computing the wholesale level order quantity, reorder point, repair quantity, and repair level. This study doesn't address receiver reorder points, receiver safety stocks, or other levels functions.

B. LEVELS MODEL ASSUMPTIONS

The development of the UICP formulas for inventory levels follows the approach used by Hadley and Whitin in Chapter 4 of Reference 4. The assumptions are: [Ref. 1: p. 3-A-1]

- A continuous review system is in place. The current SPCC model assumes inventory requirements and assets are known at all times.
- A steady state environment exists. That is, the model assumes that the average values and variances for demand, procurement lead time, production lead time, repair times, repair survival rates, and carcass return rate are constant over the forecast period.
- Customer demands and carcass returns occur one unit per transaction. Combined with the continuous review assumption, this means a procurement or repair order is placed as soon as assets reach the reorder or repair level.
- There are no quantity discounts. That is, the procurement or repair cost is independent of the order or repair quantity.

- The backorder or shortage cost can be quantified. SPCC assigns an implied shortage cost to each group of DLRs having the same four-digit cognizance symbol. The implied shortage costs change as the budget dollars change. The use of the implied shortage cost to keep levels within budget is discussed near the end of the next section on SPCC model theory.
- The reorder level and repair level are always greater than or equal to zero.
- The inventory holding cost is a percentage of the item's unit cost.
- No interaction exists among families of items or individual non-family items. A family is a group of two or more items that have an interchangeable or substitute relationship [Ref. 1: p. 3-53]. Simply stated, inventory levels are calculated independently for each item, but levels combines the demand, frequency, carcass returns, and other observations of all family items to compute one forecast for the family head or most preferred item [Ref. 5: p. 3-1].
- The optimal inventory levels are determined by minimizing the average annual variable costs. The annual variable costs consist of ordering, holding, and shortage costs. It should be noted that the UICP levels are not necessarily optimal because SPCC uses approximations in computing the levels and then places constraints on the computed levels.
- The relative military worth or essentiality of an item can be quantified on a relative scale from 0 to 1. That is, an item's worth is based on the impact of the item's failure on mission accomplishment. If an item's failure would cause the loss of a major mission capability, that item's essentiality would be set high (i.e., close to one); whereas, if an item's failure would have no impact on mission capability, that item's essentiality would be set low (i.e., close to 0). Even though the current levels program can accommodate essentiality as a variable, essentiality is assigned a constant value of 0.5 for all SPCC managed items (i.e., DLRs and consumables) [Ref. 6].
- There are no funding limitations. This assumption is very unrealistic. As discussed with the shortage cost assumption, budgets do effect levels.
- Probability distributions of lead time demand are normal or negative binomial. As seen in Table 1, the Poisson distribution isn't used to compute repairable levels.

C. SPCC MODEL THEORY

1. Introduction

The current SPCC DLR inventory model uses the quarterly forecasts generated in the first part of the levels program to compute the following for each DLR:

- Procurement quantity (How much to buy?)
- Procurement reorder level or point (When to buy?)
- Repair quantity (How much to repair?).
- Repair level (When to repair?).

Before 1984, SPCC used two separate models: one for procurement quantity and level, as well as one for repair quantity and level [Ref. 7]. However, the independent

models may have been causing a carcass constrained situation. That is, the procurement levels did not provide enough carcasses to meet the computed repair inventory levels [Ref. 1: p. 3-A-13].

In retrospect, the shortage of carcasses was more likely caused by the fleet's failure to return carcasses for repair [Ref. 3]. Before the procurement of DLRs migrated from Appropriation Purchases Account (APA) to Navy Stock Account (NSA) funding in the early 1980s, the average ship had little incentive to return failed units since it didn't pay for them.

Regardless of the reasons, SPCC implemented an integrated DLR model in 1984 [Ref. 7]. The integration of the two models was accomplished by using one stockout risk equation and an average acquisition time horizon for the reorder and repair level computations [Ref. 1: p. 3-A-13]. The following sections explain the steps taken in computing levels using this integrated DLR model.

2. Total Variable Cost Equation

As stated in the assumptions, this model minimizes total annual variable costs (TVC). The TVC equation used to develop the levels formulas for the integrated repairables model is: [Ref. 8 : p. 5]

TVC = Ordering Costs + Holding Costs + Shortage Costs

$$= \left[\frac{4(D-G)}{Q} A + \frac{4G}{Q_2} A_2 \right]$$

$$+ \left[IC\left(\frac{Q}{2}\right) + IC_2\left(\frac{Q_2}{2}\right) + IC_3(R - DL + GL - GT + B_1) \right]$$

$$+ \left[\lambda E \frac{F}{D} B_1 \right].$$

This TVC equation really just integrates the procurement problem TVC equation and the repair problem TVC equation of the previous version of the repairables model. The costs that compose this integrated TVC equation are defined as follows: [Ref. 1: p. 3-A-11]

- Ordering cost = $\dfrac{4(D-G)}{Q} A + \dfrac{4G}{Q_2} A_2$;

  where:

  $\dfrac{4(D-G)}{Q}$ = Expected number of procurement orders in a year;

D-G = Attrition demand forecast;

D = Quarterly demand forecast;

G = Quarterly regenerations forecast;

Q = Attrition (procurement) order quantity;

A = Administrative ordering cost + manufacturer's setup cost;

$4G/Q_2$ = Expected number of repair batches in a year;

Q_2 = Repair quantity;

A_2 = Repair ordering cost + repair setup cost.

A regeneration forecast is the quantity of an item that we expect will be repaired and returned to the wholesale inventory during the quarter. Since demand (D) represents the number coming out of stock and regenerations (G) represents the number being put back into stock from repair, attrition demand ($D - G$) is the net number of an item being removed from stock during the quarter that must be replenished through procurement.

- Holding cost = $IC(Q/2) + IC_2(Q_2/2) + IC_3(R - DL + GL - GT + B_1)$;

  where:

I = Inventory holding cost rate (Fixed at .21 for DLRs);

C = Item procurement unit cost;

C_2 = Item repair unit cost;

C_3 = $\left(\frac{G}{D}\right)C_2 + \left(1 - \frac{G}{D}\right)C$;
= Item's weighted average unit cost;

R – DL + GL – GT = The expected safety stock;

R = Inventory position reorder point or level;

L = Procurement lead time;

DL = Expected demand during procurement lead time;

GL = Expected regenerations during procurement lead time;

T = Repair cycle time = time to repair + time between scheduled repairs;

GT = Expected regenerations during the repair cycle time;

B_1 = Expected number of units on backorder at any random point in time.

A backorder occurs when a material request from a customer can't be immediately satisfied, so the material request is suspended until stock is received

[Ref. 1: p. A-3]. The UICP program approximates B_1 by using expected number of units backordered in an order cycle. That is:

$$B_1 = \int_R^\infty (X - R)F(X;L_3)dx;$$

where:

X = A random variable representing demand during resupply lead time;

L_3 = Resupply lead time.

B_1 is an approximation that prevents difficulties in taking derivatives. Also note that, in reality, X is a discrete random variable. A continuous function is used as an approximation to simplify computations. Also, the resupply lead time is the average time to resupply the stock of a DLR, and can be expressed as the sum of the average time for repair and the average time to procure new assets. That is:

$$L_3 = \frac{G}{D}T + \left(1 - \frac{G}{D}\right)L.$$

The reasoning behind the holding cost equation is easier to comprehend if the equation is broken down into parts. To get a holding cost in dollars, the equation must contain a dollars/unit element and a quantity or number of units element. IC, IC_2, and IC_3 represent the dollars/unit elements, while Q/2, $Q_2/2$, and $R - DL + GL - GT + B_1$ represent the average or expected number of RFI and NRFI units on hand during the year. Applying three different holding cost rates clouds the inventory position (IP) theory on which the holding cost is based. The following paragraphs explain the use of inventory position in the holding cost portion of the TVC equation.

Note that the expression for safety stock, $R - DL + GL - GT$, can be expressed as:

$$R - [(D - G)L + GT].$$

Also, inventory position (IP) is defined as the on hand (OH) plus on order (OO) minus backorders (BO) [Ref. 9: p. 94]. That is:

$$IP = OH + OO - BO.$$

Therefore, the expected on hand or E(OH) is:

$E(OH) = E(IP) - E(OO) + E(BO);$

$$= Q/2 + Q_2/2 + R - [(D - G)L + GT] + B_1.$$

Breaking down the equation for E(OH):

$E(IP) = Q/2 + Q_2/2 + R;$

$E(OO) = (D - G)L + GT;$

$E(BO) = B_1.$

The E(IP) term represents an average RFI inventory position. The E(OO) term may not make sense at first glance, but if the regenerations (G) were zero, E(OO) = DL or demand during lead time. So, the E(OO) term can be thought of as the lead time demand for a DLR [Ref. 4: p. 187]. SPCC refers to the E(OO) term as the procurement problem variable (Z) [Ref. 1: p. 3-A-8]. Mathematically then:

$E(OO) = Z = (D - G)L + GT.$

E(OO), or Z, can be derived as follows: [Ref. 3]

Let:

CRR = Carcass return rate. This is the expected percentage of quarterly demands for which the fleet will return a carcass.

RSR = Repair survival rate. This is the expected percentage of carcasses received at the DOP that will be repairable (i.e., survive the repair process at the DOP) and be returned to RFI condition.

With these two terms defined, regenerations can be expressed as:

$G = CRR \times RSR \times D.$

Note that if the fleet turns in all carcasses for each DLR issued from stock, CRR = 1. If all of these turned-in carcasses survive the repair process, RSR = 1 and G = D. That is, attrition is zero.

Using algebra, the percentage of regenerated assets can be expressed as:

$$\frac{G}{D} = CRR \times RSR,$$

and it follows that 1 - G/D is the percentage of attrition. Recalling that Z can be thought of as the lead time demand for a DLR:

$$Z = D \times \text{Resupply Lead Time} = D \times L_3$$

or

$$Z = D \times \left[\frac{G}{D} T + \left(1 - \frac{G}{D}\right) L \right]$$

or

$$Z = GT + DL - GT.$$

Although it may also seem strange that the backorder term is included in the holding cost equation, B_1 must be included when defining the expected number of units on hand in terms of inventory position.

- Shortage Cost $= \lambda E \dfrac{F}{D} B_1$;
  where:

  λ = Shortage cost per requisition backordered;

  E = Item military essentiality (currently 0.5 for all items);

  F = Quarterly requisition frequency forecast (i.e., requisitions per quarter).

SPCC assigns a unique λ to each four-digit cognizance symbol group. That is, all items having the same four-digit cognizance symbol have the same λ.

To summarize:

$$\text{TVC} = \frac{4(D-G)}{Q} A + \frac{4G}{Q_2} A_2 \tag{1}$$

$$+ IC\left(\frac{Q}{2}\right) + IC_2\left(\frac{Q_2}{2}\right) + IC_3(R - DL + GL - GT + B_1)$$

$$+ \lambda E \frac{F}{D} B_1.$$

3. Deriving the Procurement Order Quantity (Q)

Taking the partial derivative of TVC with respect to the procurement order quantity, Q:

$$\frac{\partial TVC}{\partial Q} = \frac{-4(D-G)}{Q^2}A + \frac{IC}{2}.$$

Setting $\frac{\partial TVC}{\partial Q} = 0$ and solving for the economic order quantity (Q):

$$Q = \sqrt{\frac{8(D-G)A}{IC}}. \tag{2}$$

Note that this formulation of Q is not really optimal because the correct form of the shortage cost, which should have been used by the ICPs in Equation (1), is also a function of Q. An optimal solution would involve the inclusion of this shortage cost term in Equation (2) and would require using an iterative approach to solve for Q.

4. Deriving the Procurement Reorder Level (R)

The reorder level is calculated using the stockout risk and either the normal or negative binomial distribution. The formula for the integrated stockout risk is derived by taking the partial derivative of TVC with respect to the reorder level, R, as follows:

$$\frac{\partial TVC}{\partial R} = IC_3 + IC_3\frac{\partial}{\partial R}\int_R^\infty (X-R)F(X;L_3)dx + \frac{\lambda EF}{D}\frac{\partial}{\partial R}\int_R^\infty (X-R)F(X;L_3)dx;$$

$$= IC_3 + \left[IC_3 + \frac{\lambda EF}{D}\right]\frac{\partial}{\partial R}\int_R^\infty (X-R)F(X;L_3)dx.$$

Using Leibnitz' rule:

$$\frac{\partial TVC}{\partial R} = IC_3 - \left[IC_3 + \frac{\lambda EF}{D}\right]\int_R^\infty F(X;L_3)dx.$$

Setting $\frac{\partial TVC}{\partial R} = 0$ and solving for the stockout risk: [Ref. 1: p. 3-A-13]

$$\text{Risk} = \int_R^\infty F(X;L_3)dx = \frac{DIC_3}{DIC_3 + \lambda EF}.$$

After this integrated Risk equation is calculated, it is further constrained by the ICPs. [Ref. 1: p. 3-A-16] If the calculated risk is below an ICP minimum risk value, risk is set equal to the minimum risk value. If the calculated risk is above an ICP maximum risk value, risk is set equal to the maximum risk value. These minimum and maximum

risk values are set to the same values for each item in a four-digit cognizance symbol (COG) group.

After the constrained risk value is derived, the procurement problem variable (Z) is calculated as discussed on page 14. Z is then compared to what SPCC calls a Probability Break Point (PBP) value to decide which distribution (i.e., normal or negative binomial) to use in calculating the attrition reorder level. SPCC assigns unique PBPs to each four-digit COG so that every DLR having the same four-digit COG has the same PBP. SPCC currently sets PBP = 0 for 87 of the 104 four-digit COGs for DLRs. In general, faster moving items have PBP = 0 so that the normal distribution is used to calculate the reorder level. If Z $\geq$ PBP, the basic reorder point (R) is computed as: [Ref. 10: p. M-1]

$$R = Z + z\sigma; \tag{3}$$

where:

Z = Procurement problem variable;

z = The appropriate normal deviate;

σ = Procurement problem standard deviation;

$z\sigma$ = Safety stock.

The formula for σ is a function of the same variables that determine the procurement problem variable (Z) [Ref. 1: p. 3-A-43].

If Z < PBP, the negative binomial distribution is used to compute the reorder level (R). In that case, R is the smallest value such that: [Ref. 10: p. M-3]

$$P(X \leq R) \geq 1 - \text{Risk}. \tag{4}$$

The negative binomial density function is: [Ref. 11: p. 122]

$$f(x) = \binom{x-1}{k-1} \rho^k (1-\rho)^{x-k}, \quad \text{for } x = k, k+1, k+3, ...,$$

where both x and k are integer values. However, the ICPs use the following recursion formula to approximate the negative binomial distribution, which ignores the requirement that k be an integer: [Ref. 3]

$$P(X = x) = \left\{ \frac{(x+k-1)}{x} \right\} (1-\rho) P(X = x-1);$$

where:

$P(X = 0) = \rho^k;$

$\rho \quad = \frac{Z}{\sigma^2};$

$\sigma^2 \quad$ = Procurement problem variance;

$k \quad = \frac{Z^2}{(\sigma^2 - Z)}.$

5. Deriving the Repair Quantity (Q_2).

Taking the partial derivative of TVC with respect to the repair quantity, Q_2 :

$$\frac{\partial TVC}{\partial Q_2} = \frac{-4G}{Q_2^2} A_2 + \frac{IC_2}{2}$$

Setting $\partial TVC / \partial Q_2 = 0$ and solving for Q_2:

$$Q_2 = \sqrt{\frac{8GA_2}{IC_2}}.$$

However, SPCC constrains G so that $G \leq D$ and uses the following formula for the repair quantity: [Ref. 8: p. 5]

$$Q_2 = \sqrt{\frac{8\,min(D,G)A_2}{IC_2}}.$$

6. Deriving the Repair Level (R_2)

Recall that under the integrated model, only one risk equation is used. That is, a new risk equation is not derived for computing R_2. Instead, SPCC computes R_2 as follows: [Ref. 1: p. 3-A-14]

$$R_2 = DT + R - Z;$$

where:

DT = Demand during repair problem turnaround time;

$R - Z$ = Safety stock from the procurement part of the problem.

To understand the reasoning behind this formulation for R_2, assume that a normal distribution was used to calculate the reorder level (R) for a particular DLR. Substituting equation (3) on page 16 for R, R_2 can be expressed as:

$$R_2 = DT + z\sigma.$$

Recall that the integrated stockout risk equation is used to find the z value and that $z\sigma$ represents the safety stock. Thus, under the integrated model, R and R_2 have a common safety stock. So, R_2 simply consists of a quantity of stock available for issue while carcasses are being repaired (DT) and a safety stock quantity ($R - Z$ or $z\sigma$) to provide protection against stockouts caused by variations in demand or repair turn-around time.

7. Summary

The theory behind the current SPCC integrated DLR model is to minimize TVC. In reality, however, SPCC actually tries to maximize supply material availability (SMA) subject to a budget constraint. The use of the implied shortage cost (λ) is the key to understanding what is really happening.

Recall that the risk equation is:

$$\text{Risk} = \frac{DIC_3}{DIC_3 + \lambda EF} .$$

An increase in λ means that the risk decreases. If risk decreases, the safety stock (thus reorder level (R)) increases and SMA will improve. This makes sense since the higher the stockout cost, the more a stockout should be avoided. However, λ can only be increased if funds are available to purchase the increased safety stock.

As an example, assume an item's reorder level is computed using the normal distribution and that initially, risk = 0.50, the procurement problem variable (Z) = 10, and the procurement problem variance (σ^2) = 4. Using the risk value and the normal distribution, the normal deviate (z) = 0. Thus, using equation (3) on page 16:

$$R = Z + z\sigma;$$

$$= 10 + 0(2) = 10 \text{ units.}$$

If the shortage cost (λ) were increased such that risk = 0.3085, the normal deviate (z) will now be 0.5 and:

$$R = 10 + 0.5(2) = 11 \text{ units.}$$

Thus, increasing the shortage cost, in this example, caused an increase in the safety stock of one unit.

To summarize, SPCC uses the following equations to compute levels for each DLR:

- Procurement Order Quantity (Q)

  $$Q = \sqrt{\frac{8(D-G)A}{IC}}.$$

- Risk $= \dfrac{DIC_3}{DIC_3 + \lambda EF}$.
- Procurement Reorder Level (R)

  Using the normal distribution:

  $$R = Z + z\sigma.$$

  Using the negative binomial distribution:

  R = the smallest value such that:

  $$\sum_{x=0}^{R} P(X = x) \geq 1 - \text{Risk}.$$

- Repair Quantity (Q_2)

  $$Q_2 = \sqrt{\frac{8\,min(D,G)A_2}{IC_2}}.$$

- Repair Level (R_2)

  $$R_2 = DT + R - Z.$$

D. SPCC DLR MODEL CONSTRAINTS

Once the values of Q, R, Q_2, and R_2 are calculated for all items from the formulas just discussed, constraints are applied to these values to get the final levels for each item.

1. Constrained Procurement Order Quantity ($\hat{Q}$).

[Ref. 5: pp. O-23, O-46]

If $D \leq G$ then:

$$\hat{Q} = 1.$$

If a Life Of Type (LOT) quantity exists, then:

$$\hat{Q} = \text{LOT quantity}.$$

The LOT quantity of an item is the quantity required to sustain operations of a weapon system or end item throughout its life [Ref. 1: p. A-9].

For D > G:

$$\hat{Q} = min \begin{bmatrix} min \begin{bmatrix} 12(D-G) \\ max \begin{Bmatrix} K_0(D-G) \\ Q \end{Bmatrix} \end{bmatrix} \\ 4S(D-G) - max \begin{Bmatrix} \hat{R} - Z \\ 0 \end{Bmatrix} \end{bmatrix};$$

where:

$12(D-G)$	=	Twelve quarters or three years of attrition demand;
$K_0(D-G)$	=	Minimum buy quantity in terms of attrition demand;
K_0	=	Discount quantity. Usually $K_0 = 0$, but if zero, the levels program sets $K_0 = 1$;
Q	=	Order quantity computed in equation (2) on page 15;
S	=	Shelf life in quarters;
$\hat{R}$	=	Constrained procurement reorder level. To be discussed in the next section.

Although discount quantity is the term used by FMSO for K_0 [Ref. 5: p. O-23], this terminology is misleading since $K_0(D-G)$ really represents the minimum buy quantity in terms of quarters of attrition demand.

2. Constrained Procurement Reorder Level ($\hat{R}$).

[Ref. 5: p. O-44]

If a LOT quantity exists then:

$$\hat{R} = 0.$$

If $Z \leq 0$ then:

$$\hat{R} = Max\,(NSO,\ 0).$$

Otherwise:

$$\hat{R} = max \begin{bmatrix} 0 \\ K_1 Z \\ NSO \\ min \begin{bmatrix} Z + K_2 D \\ max \begin{Bmatrix} R \\ NRPR \end{Bmatrix} \\ 4DS + Z - K_0(D - G) \end{bmatrix} \end{bmatrix};$$

where:

K_1 = Reorder level constraint rate. Assigned by four-digit COG, SPCC sets K_1 equal to one or zero. Currently, $K_1 = 1$ for 87 of 104 four-digit COGs for DLRs. For those DLRs where $K_1 = 1$, $\hat{R}$ is forced to be at least as big as Z.

NSO = Numeric stocking objective. A value to ensure a minimum stocking level.

K_2 = Maximum number of quarters of safety stock acceptable. $K_2 = 20$ for all items [Ref. 7].

R = Basic procurement reorder level computed using equation (3) or (4) on page 16.

NRPR = Number of policy receivers. The number of stock points that, by policy, will stock this wholesale inventory item.

3. Constrained Repair Quantity ($\hat{Q}_2$).

[Ref. 10: p. K-11]

If SPCC is the Secondary Inventory Control Activity (SICA), then $\hat{Q}_2 = 0$. When SPCC has Aviation Supply Office (ASO) managed material installed in an SPCC managed equipment, SPCC is the SICA for the ASO managed item. That is, ASO has primary responsibility for the item, which includes scheduling the repair of all carcasses. Thus, SPCC's repair quantity ($\hat{Q}_2$) is set to zero.

If D = 0 or G = 0 or DT = 0 then:

$$\hat{Q}_2 = 1.$$

Otherwise:

$$\hat{Q}_2 = max \begin{bmatrix} 1 & \\ min & \begin{bmatrix} Q_2 \\ 4DS - max \begin{Bmatrix} R - Z \\ 0 \end{Bmatrix} \\ LOT - DT - max \begin{Bmatrix} R - Z \\ 0 \end{Bmatrix} \end{bmatrix} \end{bmatrix};$$

where:

Q_2 = Basic repair quantity;

LOT = Life of type quantity.

4. Constrained Repair Level ($\hat{R}_2$).

[Ref. 10: p. K-11]

If SPCC is the SICA then:

$$\hat{R}_2 = 0.$$

If D = 0 or G = 0 or DT = 0 then:

$$\hat{R}_2 = max\ (DT + 0.5, 0).$$

Otherwise:

$$\hat{R}_2 = max \begin{bmatrix} 0 & \\ NSO & \\ min & \begin{bmatrix} 4DS + DT_2 - 1 \\ LOT \\ max \begin{Bmatrix} R \\ NRPR \end{Bmatrix} \end{bmatrix} \end{bmatrix}.$$

E. LEVELS PROGRAM

Appendix A contains a FORTRAN 77 program that performs the computations discussed in this chapter.

III. PROPOSED LOW ATTRITION DLR MODEL

A. BACKGROUND

As seen in Chapter II, the current SPCC DLR model has separate equations for procurement levels ($\hat{Q}$ and $\hat{R}$) and repair levels ($\hat{Q}_2$ and $\hat{R}_2$). Even though the risk equation is common to the reorder level ($\hat{R}$) and repair level ($\hat{R}_2$), two separate levels still exist.

The proposed model, like the current model, computes a reorder level for each DLR. However, if batch inductions are not used, a repair level computation isn't necessary in the proposed model because each item is inducted for repair immediately after failure. If batch inductions are used, the repair level equals the repair quantity and is very simple to compute. This process is described later in this chapter.

The simplicity of the immediate induction or batch induction process used in the proposed model is an advantage that can be clearly understood if the reader is familiar with the complex induction process currently used. The following paragraphs provide a brief and incomplete description of the current repair requirements determination process, but gives the reader an appreciation of its complexity.

SPCC's Workload Forecast (WLF) program identifies 88 percent of SPCC's repair requirements and the Repair Scheduling, or B08, program identifies the remaining 12 percent of SPCC's repair requirements [Ref. 12: pp. 1-2].

The WLF program is run every six months and is pro-active in that it tries to predict the ready for issue (RFI) inventory position for the next six months to determine the repair inductions that will be required. The required inductions are referred to as repair requirements [Ref. 12: p. 1]. The repair requirements output from the WLF program are the primary tool used by SPCC personnel at the semi-annual repair conferences. These repair conferences are discussed in greater detail in Chapter IV, but basically, these conferences are used to communicate SPCC's repair requirements for the next six months to the DOPs and to get each DOP's commitment to a repair schedule. The DOPs can induct all carcasses received up to the repair requirement quantity, but SPCC advises each DOP to do its workload planning based on the production quantity. The production quantity is the repair requirement constrained by the carcass returns and represents SPCC's best estimate of the actual carcass receipts at the DOP for the next six months [Ref. 12: p. 1].

The other source used to identify repair requirements, the Repair Scheduling or B08 program, is run biweekly. SPCC uses this program to identify sporadic repair requirements and views the program as a safety net to catch emergent requirements that couldn't be forecasted [Ref. 12 : p. 2]. Repair requirements identified by the B08 program are reviewed by the responsible item manager. For those items where an immediate need exists, SPCC attempts to get the required number of carcasses into the repair process immediately. For less critical requirements, SPCC will schedule needed repairs during the next semiannual repair conference [Ref. 13].

Both WLF and B08 compare assets with requirements to see if a repair induction is required. WLF, however, is pro-active, while B08 is reactive. That is, WLF predicts the repair requirements for the next six months, while B08 uses past data to calculate the current repair requirement.

Although the previous paragraphs provide only a brief description of the process SPCC uses to determine repair requirements, one can see that the process is complex, requires a large staff of people at SPCC to make it work, and isn't exact due to the nature of forecasting.

As stated earlier, the proposed model greatly simplifies the repair induction process. The model assumes that the repair quantity is one and repairs are done as any DLR fails (i.e., $\hat{Q}_2 = 1$), or that repairs are accomplished when the number of failed DLRs reaches a set level (i.e., $\hat{Q}_2 =$ batch induction quantity). So, management must decide whether or not batch induction is desired and, if desired, the batch induction quantity for each item must be determined. The major drawback would be the initial repair budget required to repair the existing backlogs of not ready for issue (NRFI) carcasses.

The proposed model is similar to the current DLR model in that both compute a reorder level and an attrition order quantity, but the proposed model uses queueing theory to integrate the repair process into the inventory model. The proposed model also depends on total asset visibility. Total asset visibility means that the on hand assets at all levels--wholesale, retail intermediate, and retail consumer--are known along with the total installed population and the number of NRFI units at repair facilities and stock points. While total asset visibility is not readily available at present, this information can be estimated. More exact asset visibility procedures are being developed as part of the Navy's Secondary Item Weapon System Management (SIWSM) initiative [Ref. 2: pp. 5 and D-1]. As information improves, so will the performance of the proposed model.

Past work on models similar to the proposed model has been done by Gross, Miller, and Soland [Ref. 14], Gross [Ref 15], Graves [Ref. 16], Moinzadeh and Lee [Ref. 17], and Sherbrooke [Ref. 18]. All of the past work, however, assumes that no attrition exists. That is, all carcasses entering repair are returned to RFI condition. The proposed model doesn't make this assumption.

Graves' article, "A Multi-Echelon Inventory Model for a Repairable Item with One-For-One Replenishment," describes an inventory process using a closed queueing system with a finite number of servers. He refers to this model as the exact model. He then compares the exact model to a model that uses a negative binomial distribution and a model called METRIC that uses a queueing system that assumes an infinite number of servers [Ref. 16: pp. 1248-1251]. Although Graves implies that when there are actually a finite number of servers at a repair facility, the best model is the exact model, the negative binomial and METRIC approximations are far less complex and are currently being used. For the 1968 test cases used, Graves found the negative binomial approximation resulted in stockage quantities different from the exact model only 0.9 percent of the time and that the METRIC stockage quantities differed from the exact model 11.5 percent of the time [Ref. 16: p. 1253].

Sherbrooke's, "Vari-METRIC: Improved Approximations for Multi-Indenture, Multi-Echelon Availability Models," article presents a model that improves on the earlier METRIC model and shows that as an approximation to the exact model presented by Graves, Vari-METRIC improves on METRIC and provides results almost equal to the negative binomial model presented by Graves [Ref. 18: p. 311].

In his article, "On the Ample Service Assumption of Palm's Theorem in Inventory Modeling," Gross contends that for most repairable item inventory control processes, the assumption that items to be repaired never queue up, but go into repair immediately, is false. [Ref. 15: pp. 1065-1067] Gross then shows that incorrectly assuming unlimited repair capacity will cause measures of effectiveness, such as fill rate, to have overly optimistic values.

In "A Closed Queueing Model for Multi-echelon Repairables Item Provisioning," Gross, Miller, and Soland presented a closed queueing network theory to model the stochastic inventory process. [Ref. 14: p. 344] They studied how to determine the optimal spares levels and repair capacities for a repairable item, multi-echelon system in which a finite number of operational items are desired at any given time and in which queueing may occur at the repair facilities when all repair channels are busy.

In "Batch Size and Stockage Levels in Multi-Echelon Repairable Systems," Moinzadeh and Lee contend that for multi-echelon repairable inventory systems with high ordering costs or high demand rates or both, the use of a batch ordering policy may be more cost effective than the common one-for-one ordering policy [Ref. 17: p. 1579]. The case presented by Moinzadeh and Lee is evidence that batch repair in the proposed model presented in this thesis may also be cost effective where high repair set up costs or high demand rates or both are in evidence.

To summarize, the articles by Graves and Sherbrooke promote using approximations to what they refer to as an exact model. This exact model uses a queueing model with a finite number of servers. The queueing theory used for Graves' and Sherbrooke's exact model is identical to the queueing theory used in the proposed model presented here. The approximations use queueing models that assume an infinite number of servers or repair channels and have the advantage of computational simplicity.

Gross points out that when the ample server (i.e., infinite number of servers) assumption doesn't hold, the approximate models' anticipated inventory effectiveness can be significantly overstated. Gross, Miller, and Soland present an inventory control process using a queueing model having a finite number of servers.

Finally, Moinzadeh and Lee present a case for using a batch ordering policy that can be extended to using a batch repair induction policy when cost efficient.

The proposed model presented in this chapter takes an approach similar to Gross, Miller, and Soland. After discussions with repair depot personnel, it is clear that the finite server case certainly applies to the repair facilities used by the Navy.

B. MODEL ASSUMPTIONS

The following assumptions apply to the proposed model: [Ref. 19]

- A continuous review control process exists.
- A single echelon of inventory exists. In this case, the model deals with the wholesale inventory level.
- One or more stock keeping units or National Stock Numbers (NSN) of DLRs are stocked.
- The inventory managers are concerned about costs and about operational availability of the equipment into which the DLRs are installed.
- Repair facilities, inventories of spare DLRs, and repairable equipment are located in the same general area so that transportation costs and times are negligible.
- Failed DLRs can be repaired most, but not all of the time. That is, the DLRs suffer low attrition.

- A M/M/1/K/K or M/M/c/K/K queueing model is appropriate for the repair process. This means that failures, and thus arrivals for repair, follow a poisson process (i.e., interarrival times are exponentially distributed). Service times are exponentially distributed. The system capacity is limited to K units and there are K units in the population source that feeds the repair facilities.
- The item manager (IM) at the ICP has total asset visibility. That is, the IM has access to information that tells him or her the number of installed units, wholesale Ready For Issue (RFI) units, retail intermediate RFI units, retail consumer RFI units, and NRFI units.
- The IM has visibility of other variables such as number of repair channels, failure rates, and service times.
- NRFI DLRs enter the repair process as soon as they are removed and sent to the repair depot. This is a radical change in philosophy. Under this model, there is no need to calculate a repair quantity or repair level since a unit enters the repair process as soon as it fails. As already noted, the model can be adapted to use batch inductions to the repair process.
- A steady state situation exists.

C. PROPOSED MODEL THEORY

The proposed model assumes either a M/M/1/K/K or M/M/c/K/K queueing system for the repair process. The theory behind these models is described in this section.

1. Kendall Notation

M/M/1/K/K and M/M/c/K/K represent a shorthand notation developed by David Kendall for describing queueing models having specific characteristics. The following is a breakdown of the shorthand notation used in this thesis: [Ref. 20: p. 157]

- M -- When used in the first position of Kendall's notation, M means that the process assumes an exponential distribution for interarrival times.
- M -- When used in the second position of Kendall's notation, M means that the process assumes an exponential distribution for service times.
- c -- When used in the third position of Kendall's notation, c refers to the number of servers or repair channels.
- K -- When used in the fourth position of Kendall's notation, K defines the system capacity or maximum number of customers allowed in the system. A customer in this case is a failed DLR.
- K -- When used in the fifth position of Kendall's notation, K defines the number of customers in the source population. In this case, there is a finite number of each DLR that could possibly be repaired. This quantity, K, is the number of each DLR that the Navy owns.

2. Queueing Model Notation

The following notation is used in the queueing systems used in this model: [Ref. 20: p. 352]

c	=	Number of identical repair channels;
μ	=	Average repair rate per repair channel;
α	=	Average failure rate of an individual DLR;
N	=	Random variable describing the steady state number of NRFI units;
P_n	=	Steady state probability that there are n NRFI units;
$1/\mu$	=	Expected repair time;
$1/\alpha$	=	Expected interfailure time or Mean Time Between Failures (MTBF).

3. The M/M/1/K/K Queueing System

This system is often called the machine repair queueing system with one repairman. The following description refers to the diagram of this system shown in Figure 2. [Ref. 20: pp. 187-190]

The population of potential customers consists of K identical machines or DLRs. DLR's have an operating time between failure which is exponentially distributed with a MTBF = $\frac{1}{\alpha}$. The one server repairs the DLRs at a rate (μ) that is exponentially distributed with a Mean Time To Repair (MTTR) = $\frac{1}{\mu}$. Referring to Figure 3, the queueing system is inside the box formed by the dashed lines; therefore, the operating machines or DLRs are outside the system and enter only when they fail. This model always reaches steady state because there can be no more than K (the number we own) DLRs in the system. Steady state means that the influences of the initial or start up conditions have smoothed out and the probability that a certain number of DLRs are in the system and in the queue is independent of time. When the queueing system is first put into operation, and for some time afterwards, the number in the queue and in service depends strongly on both the initial conditions (such as the number of customers queued up waiting for the system to begin operation) and how long the system has been operating [Ref. 20: p. 152].

When N machines or DLRs have failed, $K - N$ are operating or are RFI. The time until the next DLR fails is the minimum of $K - N$ identical exponential distributions; thus, the time until the next DLR fails is exponentially distributed with parameter $(K - N)\alpha$ and the probability, P_n, that n DLRs have failed (n being the number of units in the queueing system) is:

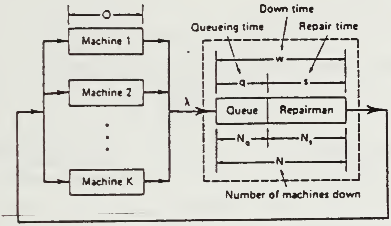

Figure 2. Machine Repair Queueing System With One Repairman (M/M/1/K/K)

$$P_n = \frac{K!}{(K-n)!} \left(\frac{\alpha}{\mu}\right)^n P_0 \, ;$$

where:

$$P_0 = \left[\sum_{n=0}^{K} \frac{K!}{(K-n)!} \left(\frac{\alpha}{\mu}\right)^n \right]^{-1} ;$$

and

P_0 = The probability that zero units are in the queueing system.

4. The M/M/c/K/K Queueing System

This system is exactly like the M/M/1/K/K system except that there are c repairmen rather than one and $c \leq K$. A diagram of this system is shown in Figure 3 [Ref. 20: p. 191]. Here, the probability that there are n DLRs in the queueing system is: [Ref. 20: pp. 190-192]

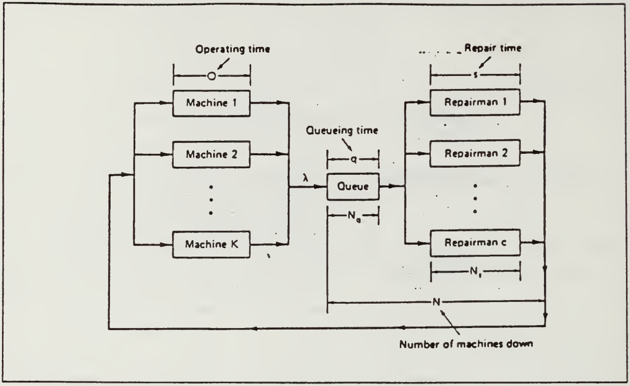

Figure 3. Machine Repair Queueing System With c Repairmen (M/M/c/K/K)

$$P_n = \binom{K}{n}\left(\frac{\alpha}{\mu}\right)^n P_0, \qquad \text{for } n = 0,1,\ldots,c,$$

and,

$$P_n = \frac{n!}{c!c^{n-c}}\binom{K}{n}\left(\frac{\alpha}{\mu}\right)^n P_0, \qquad \text{for } n = c+1,\ldots,K;$$

where:

$$P_0 = \left[\sum_{n=0}^{c}\binom{K}{n}\left(\frac{\alpha}{\mu}\right)^n + \sum_{n=c+1}^{K}\binom{K}{n}\left(\frac{\alpha}{\mu}\right)^n \frac{n!}{c!c^{n-c}}\right]^{-1}.$$

D. PROPOSED DLR MODEL

The proposed model consists of three steps: [Ref. 19]

1. Compute the target, minimum population size (K_i).
2. Compute the reorder point (R_i).
3. Compute the reorder quantity (Q_i).

The subscript i used with each of the variables in the proposed model identifies an individual DLR in the set of n possible different DLRs being considered in the inventory control process (i.e., i = 1,2,...,n).

The target minimum population size (K_i) is a level of inventory that consists of installed units, RFI spares, and NRFI spares for DLR i. The spares in K_i can be thought of as safety stock. As the reader will see in subsequent sections, K_i is calculated using a machine repair queueing model. This machine repair queueing model assumes that there is no attrition in the short term and that the repair facility has a finite number of servers or repair channels. Stated simply, the queueing model is used to find the minimum stockage level (K_i) for each DLR i such that the probability of having more broken units than spares is less than a specified maximum shortage probability.

The reorder point (R_i) for each DLR i, represents a quantity of stock, to be owned over and above the K_i population quantity, that equals the expected mean attrition demand during procurement lead time plus or minus some additional safety stock. A negative safety stock implies that the DLR has very low demand or is not critical or both. In these cases, the item may not be stocked above the K_i level (i.e., $R_i = 0$) and the K_i level may not contain any spares. Thus, if an installed unit failed, a replacement would not be available until the failed unit was repaired or a new unit procured.

R_i is determined by using the Poisson distribution and finding the smallest value such that the probability of actual attrition demand during lead time being greater than the reorder level quantity (R_i) is less that a specific stockout risk. When the inventory position of DLR i reaches R_i, an attrition buy of Q_i units is initiated.

Initially, each DLR must have an inventory position (IP) of installed units, RFI spares, NRFI spares (including spares undergoing repair), and on order spares equal to: [Ref. 19]

$\text{Max IP}_i = K_i + R_i + Q_i$.

As attrition occurs, the inventory position is gradually reduced to a quantity equal to $K_i + R_i$. When this happens, an attrition buy of Q_i units is made. Notice that, unlike the current SPCC DLR model, inventory position does not include backorders. [Ref. 21] While the current model's inventory position only includes spares (i.e., IP = RFI spares on hand + spares on order - spares on backorder), the proposed model's inventory position includes RFI spares (on hand and on order), NRFI spares on hand, and installed units. Thus, backorders must be included in the inventory position of the current model so that demand continues to reduce the inventory position, and orders continue to be placed, after the quantity of on hand RFI spares is reduced to zero. This is not the case for the proposed model. If the on hand inventory (RFI spares and installed) in the inventory position for the proposed model ever reaches zero, not only are there no spares on hand, but there are also no installed units. If there are no installed units, then there will be no further failures and tracking backorders as part of inventory position isn't necessary.

The proposed model assumes that when an installed DLR fails and is replaced, the failed unit, or carcass, is inducted for repair immediately (i.e., don't use batch repair). In this case only the attrition inventory position is tracked for each DLR since the repair quantity is always one.

If, however, batch inductions were used, the number of failed units not already in the repair process would also have to be tracked. These non-inducted carcasses represent a second inventory position or carcass inventory position that must be tracked for each DLR. The carcass inventory position for each DLR starts at zero, but is increased as units of DLR i fail. When the number of carcasses of a specific DLR reaches or exceeds an induction level of Q_{2i} units, all carcasses are inducted for repair and the carcass inventory position is reduced to zero.

The computations of the K_i, R_i, and Q_i values are described in the following sections.

1. Step One--Compute The Target Minimum Population Size (K_i)

Here the minimum K_i is computed for each DLR such that the probability of an Out Of Commission (OOC) equipment is less than a management specified percentage. The term OOC, as used here, means that the number of broken units of DLR i is greater than the number of spares available. Thus, there is no replacement for at least one failed DLR installed in a system. Mathematically, this can be expressed as: [Ref. 19]

$$\text{Minimize} \sum_{i=1}^{n} K_i,$$

Subject To: $P(X_i > K_i - U_i) \leq b_i,$ for $i = 1,2,...,n$;

where:

n = The number of different items for which levels computations are needed;

K_i = Decision variable representing all installed units and a safety stock of RFI and NRFI units of DLR i;

X_i = The number of failed units of DLR i;

U_i = The number of installed units of DLR i;

b_i = The acceptable percentage of time the number of failed units exceeds the number of spares for DLR i. This is a management decision variable, but is treated as a system parameter in the model formulation.

Note that for future studies using a large number of items, a budget constraint must be added to this formulation. Otherwise, the decision makers who manage the supply system might be inclined to set $b_i = 0$ for all i. Notice also that:

$$P(X_i > K_i - U_i) = 1 - P(X_i \leq K_i - U_i)$$

$$= 1 - \sum_{n=0}^{K_i - U_i} P(X_i = n)$$

The calculation of $P(X_i = n)$ depends on the number of repairmen used at a particular repair depot. With one repairman, the M/M/1/K/K system formulas presented on pages 31 and 32 are used to compute P_n or $P(X_i = n)$. With c repairmen, the M/M/c/K/K system formulas presented on pages 31 and 32 a re used to compute P_n or $P(X_i = n)$.

Optimal K_i can be found using linear programming or marginal analysis. This thesis only presents the model. The optimization procedure for K_i must be developed in a future study.

2. Step Two--Compute The Incremental Reorder Point Quantity (R_i)

Here, R_i is minimized such that the probability of attrition lead time demand being greater than the reorder point quantity is less than a maximum attrition shortage probability. The Poisson probability distribution with mean $(D_i - G_i)$ is assumed. Stated mathematically: [Ref. 19]

Minimize R_i,

Subject To: $P(X_i > R_i) \leq b_2$, for $i = 1, 2, ..., n$;

where:

R_i = Decision variable representing the incremental attrition reorder point quantity for item i;

X_i = Random variable representing the attrition lead time demand for item i;

b_2 = Maximum attrition shortage probability or risk. This is a management decision variable, but is treated as a system parameter in the model formulation.

Expressing this another way, for each DLR, R_i is the smallest value such that:

$$\sum_{x_i=0}^{R_i} P(X_i = x_i) \geq 1 - b_2,$$

where:

$$P(X_i = 0) = e^{-(D_i - G_i)}$$

$$P(X_i = x_i) = \frac{(D_i - G_i)}{x_i} P(X_i = X_i - 1) \qquad \text{for } X_i = 1,2,...,R_i$$

Note that $P(X_i = 0)$ and $P(X_i = x_i)$ represent a recursion formula for the Poisson distribution.

3. Step Three--Compute The Reorder Quantity (Q_i)

The model uses the basic Wilson-Harris EOQ formula developed in the last chapter for Q_i. [Ref. 19]

$$Q_i = \sqrt{\frac{8A_i(D_i - G_i)}{IC_i}} .$$

where:

A_i = Administrative ordering cost for item i;

D_i = Quarterly demand forecast for item i;

G_i = Quarterly regenerations forecast for item i;

I = Annual holding cost rate (set at 0.21 for DLRs);

C_i = Unit cost of item i.

IV. DATA COLLECTION

A. INTRODUCTION

This chapter addresses the main objective of this thesis; namely, to determine if the data required for the proposed model are available and collectable.

The chapter begins by identifying the variables, constants, and comparison data required for the current and proposed models. Sample size determination and National Stock Number (NSN) selection are then discussed, followed by a review of the initial data collection difficulties and how these data collection problems were handled.

The last two sections of the chapter discuss and present the sample data collected for the current SPCC levels model and the proposed model.

Although there were difficulties in collecting the data required for the proposed model, the author was able to find sources for the required data for all but one NSN in the sample. This doesn't mean that there are no remaining data collection problems. As the reader progresses through this chapter, it becomes apparent that for a large data sample, many problems remain for future study.

B. VARIABLES, CONSTANTS, AND COMPARISON DATA REQUIRED

1. Data Requirements for the UICP Emulation Program

Data required for the UICP levels emulation program in Appendix A were broken into four categories.

- System constants -- Those input elements that are constant for all NSNs.
- Four digit cognizance symbol (COG) constants -- Those input elements that are constant for all NSNs having the same four-digit COG.
- Unique input variables -- Those input elements that vary for each NSN.
- Comparison data -- Those data elements used to compare the emulation program results with actual SPCC results.

This section briefly describes the required constants, variables, and comparison data for each of the four categories above.

a. System Constants

- Annual holding cost rate.
- Maximum number of quarters of safety stock.
- Military essentiality code (MEC).

- Administrative cost to repair one item.
- Repair review cycle time -- A constant that can be used to constrain the repair quantity.
- Administrative cost to place one procurement order.

b. Four Digit Cognizance Symbol Constants

The following constants are the same for all depot level repairables (DLRs) having the same four-digit COG.

- Probability break point -- A constant that, when compared to the procurement problem variable (Z), determines the probability distribution that is used to compute the reorder level.
- Maximum allowable stockout risk.
- Minimum allowable stockout risk.
- Shortage cost.
- Reorder level constraint value -- A constant used by the UICP program to constrain the reorder level.

c. Unique Input Variables

To support the emulation program in Appendix A, data were required for the following variables:

- Number of policy receivers -- The number of stock points that will carry wholesale inventory for a particular DLR.
- Requisition frequency average -- The forecasted number of requisitions processed per quarter.
- Procurement problem variance -- The variance in attrition demand during resupply time.
- System reorder level low limit quantity -- Also called the numeric stocking objective, this variable represents the minimum quantity of stock desired.
- Gross system demand during procurement lead time.
- Gross system demand at the end of lead time -- This is equivalent to the quarterly demand forecast.
- System ready for issue (RFI) regenerations during procurement lead time.
- System RFI regenerations at the end of lead time -- This is equivalent to the quarterly regenerations forecast.
- Gross system demand during repair turnaround time (RTAT).
- Unit procurement cost.
- Unit repair cost.
- Manufacturer's setup cost.

- Repair setup cost.
- Discount quantity -- This is not a quantity for which a price break is received, but a variable used to control the minimum buy quantity in the levels program.
- Life of type quantity -- The quantity of material required to sustain operations throughout the life of an equipment or end item.
- Four digit cognizance symbol (COG).
- Shelf life code.
- Level of authority code for the Secondary Inventory Control Activity (SICA).
- Nonconsumable item material support code -- Used in conjunction with the level of authority code to define SPCC's responsibility for a DLR.
- Acquisition advice code -- A code used by the Levels program to decide if the DLR will be purchased for stock.
- Wear out rate -- A forecast for the percentage of a particular DLR which will become unserviceable [Ref. 5: p. 3-19]

d. Comparison Data

The following data elements should be collected for each DLR so that the results of the emulation program can be verified.

- Procurement reorder quantity.
- Procurement reorder level quantity.
- Repair quantity.
- Repair level quantity.

2. Data Requirements for the Proposed Model

The following variables must be collected for all DLRs in support of the proposed model. Some of the variables, such as quarterly demand forecast, are common to the current UICP levels model and the proposed model. [Ref. 19]

- The number of repair channels or stations at each repair facility.
- The average failure rate for each DLR (when available).
- The best replacement factor (BRF) -- An estimate of the number of part replacements per year for a given equipment or part population [Ref. 22: p. 1]. For this thesis, BRF is considered for use as an estimate of the average failure rate when the failure rate data is not available.
- The average repair rate per repair channel.
- Administrative cost of placing a procurement order.
- Quarterly demand forecast for each DLR.
- Quarterly regenerations forecast for each DLR.

- Annual holding cost rate.
- Procurement unit cost of each DLR.
- The number of installed units of each DLR -- This variable is not required for levels computation, but will be required to compare the proposed model's effectiveness against the effectiveness of the current UICP model.
- The repair turnaround time (RTAT) for each DLR -- Also not required for levels computations, this variable can be used to ensure that the average repair rates from the DOPs are reasonable.

Instead of recording the quarterly demand and regeneration forecast for each DLR and subtracting these two forecasts to get an attrition demand forecast, future studies should consider using actual demand and survey data from SPCC's Transaction History File (THF) to forecast the attrition demand.

C. SAMPLE SIZE AND SAMPLE NSN SELECTION CRITERIA

The first step in collecting data for the two models was to decide on a sample size and select the sample NSNs. After several discussions with Professor Moore, the sample size selected was 12 and the 12 NSNs were selected using the following criteria:

- High Repair Survival Rate (RSR) and Carcass Return Rate (CRR).
- Some items with a high average quarterly demand, D, (i.e., $D > 5$).
- Some items with a medium average quarterly demand (i.e., $.25 \leq D \leq 5$).
- Some items with a low average quarterly demand (i.e., $D < .25$).
- Some items with a short Repair Turnaround Time (RTAT) (i.e., $RTAT < 1$ quarter).
- Some items with a medium RTAT (i.e., $1 \leq RTAT \leq 4$).
- Some items with a long RTAT (i.e., $RTAT > 4$).
- Select items from a general repair shop (i.e., a depot that performs repairs on many NSNs) and some items from a specific repair shop (i.e., a depot that performs repairs on only a few NSNs).

A sample of 12 depot level repairables (DLRs) was sufficient to meet the above criteria while keeping the size of the study manageable.

The criteria requiring all sample items to have a high RSR[2] and a high CRR[3] was necessary since the proposed model is designed for DLRs having a low attrition rate.

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2 RSR is defined as the percentage of items inducted for repair that can be expected to be returned to RFI condition. [Ref. 5: p. 3-16] The RSR calculation only includes surveys at the depot level.

3 CRR, as used here, is a percentage equal to $(1 - WOR)/RSR$. The wear out rate (WOR)

Finally, the criteria concerning a general repair shop versus a specialized repair shop was intended to identify any major differences in service times and procedures, as well as identify data availability differences and impact on model assumptions.

Once the sample size and selection criteria were chosen, a Computation And Research Evaluation System (CARES) data base containing 30,884 7H COG NSNs was examined to get a count of the number of DLRs having a RSR greater than or equal to 0.85, 0.90, 0.95, 0.98, and 0.99. This particular CARES data base was from the spring 1988 run at SPCC and was provided by Professor A. W. McMasters. The results of these queries are presented in Table 2 and one of the selection programs used is shown in Appendix B.

The CARES data base contains RSR values, but not CRR values; therefore, for this thesis, CRR was estimated as G D x RSR [Ref. 3], where G represents the quarterly regenerations forecast. DLRs having a RSR value and a CRR value greater than or equal to 0.99 were considered to have a low attrition rate.

Table 2. 7H COG NSN BREAKDOWN BY RSR

RSR ≥	Number of 7H COG NSNs Out of 30,884	Percent of all 7H COG NSNs
0.85	25,931	83.96
0.90	19,168	62.06
0.95	8,381	27.14
0.98	2,819	9.13
0.99	2,172	7.03

Using the 2172 candidate items having a RSR ≥ 0.99, separate selection programs were used to break the candidate items into different combinations of RTAT and Quarterly Demand (D). Table 3 shows the number of items in each category and a sample selection program is presented in Appendix C.

is defined as the percentage of items inducted for repair that can be expected to become NRFI. [Ref. 5: p. 3-19] The WOR includes surveys from all maintenance levels.

Table 3. BREAKDOWN OF 7H COG NSNS HAVING A HIGH RSR

	Low Demand (D < 0.25)	Medium Demand ($0.25 \leq D \leq 5$)	High Demand (D > 5)	Totals
Short RTAT (RTAT < 1 Qtr)	116	132	28	276
Medium RTAT ($1 \leq RTAT \leq 4$)	873	874	120	1867
Long RTAT (RTAT > 4)	10	15	4	29
Totals	999	1021	152	2172

D. INITIAL DATA COLLECTION EFFORTS AND DIFFICULTIES

From the nine categories in Table 3, 40 NSNs were randomly selected. SPCC could provide all the information needed for the current UICP model, but SPCC's Repairables Support Department (code 035) confirmed that data for the number of repair channels was not available from UICP files. That is, SPCC could not provide the data for the variable c in the M/M/c/K/K queueing model. Data for this variable, at a minimum, would have to come directly from the designated overhaul points (DOPs), i.e., the repair depots.

Next, the Master Repairables Item List (MRIL) was used to identify the DOPs for the 40 items selected. Six NSNs and two DOPs were then selected for initial investigation. At this point, it was important to see how hard it would be to get information from the DOPs. Table 4 lists the six NSNs selected and their corresponding DOP from the MRIL.

The initial contact at Naval Supply Center (NSC) Puget Sound was Mr. Bill Armstrong in the Supply Support Branch (code 301.4). NSC Puget Sound was actually not the DOP, but the Designated Support Point (DSP) for the amplifier, board assembly, and electromagnetic relay listed in Table 4. A DSP is a central receiving point for DLR carcasses. If no repair requirement exists when a carcass is received, the DSP stores the item and sends a Transaction Item Report (TIR) to SPCC reporting the receipt of the material in failed condition (i.e., condition code F).[4] For the reader's

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[4] A material condition code is a single alphabetic code that indicates the various states of Ready For Issue (RFI) or Not Ready For Issue (NRFI) on hand assets in the supply system [Ref. 1: p. A-10].

reference, the condition codes most frequently used in the repair process are presented in Table 5 [Ref. 23: pp. A9-7 -- A9-8].

Table 4. MRIL SHIPPING INFORMATION FOR THE INITIAL SAMPLE

COG, Material Control Code (MCC), and NSN	Nomenclature	Designated Overhaul Point
7H H 1265-00-614-9227	Amplifier	Naval Supply Center, Puget Sound
7H H 1210-00-785-8344	Board Assembly	Naval Supply Center, Puget Sound
7H H 5945-00-790-4885	Electromagnetic Relay	Naval Supply Center, Puget Sound
7H H 2815-00-106-8060	Diesel Engine	ALCO Power, Auburn, NY
7H H 2815-01-013-5684	Diesel Engine Block	ALCO Power, Auburn, NY
7H H 2815-01-025-3819	Diesel Engine	ALCO Power, Auburn, NY

Table 5. MATERIAL CONDITION CODES USED IN THE REPAIR PROCESS

Condition Code	Condition Code Definition
A	Serviceable. New, used, repaired or reconditioned material that is serviceable and issuable to all customers without limitation or restriction.
F	Unserviceable (Repairable). Economically repairable material that requires repair or overhaul.
G	Unserviceable (Incomplete). Material awaiting additional parts or components to complete the repair.
H	Unserviceable (Condemned). Material determined to be unserviceable and uneconomical to repair.
M	Suspended (In work). Material identified on an inventory control record, but which has been turned over to a maintenance facility or contractor for repair (inducted).

When the DOP is ready to begin a repair, the DOP sends an induction order to the DSP. [Ref. 24] The DSP is responsible for getting the carcass from storage and sending it to the DOP. The DOP may be a commercial company or may be organic to the Navy or

other military service (i.e., a government run DOP such as a Naval shipyard). Once shipped, the DSP sends a TIR to SPCC reporting the item in M condition. This means that a failed carcass has entered the repair process (i.e., has been inducted).

In the case of carcasses sent to NSC Puget Sound, 90 percent of them are repaired at Naval Shipyard (NSY) Puget Sound [Ref. 24].

Assuming that the three sample items were sent to NSY Puget Sound in the past, several calls were made leading to the Electronics Repair Shop (shop 67) and its foreman Mr. Marty Levar. After researching his records for these NSNs, Mr. Levar determined that shop 67 hadn't worked on these items in the past two years. After numerous telephone calls and discussions with NSC Puget Sound, NSY Puget Sound, and SPCC personnel, it was found that no repair inductions had been made in the past two years for the following reasons: [Ref. 25]

- The amplifier, NSN 7H H 1265-00-614-9227, had 72 units in RFI or A condition and 63 units in F condition. Although demand was 5.01 units per quarter, there were plenty of RFI units on hand to meet this projected demand, so the NRFI units received were being stored at NSC Puget Sound in F condition.
- The board assembly, NSN 7H H 1210-00-785-8344, had 40 RFI units and 25 NRFI units on hand (all F condition). Demand was only 1.03 per quarter, so again, there were plenty of RFI units to meet requirements and no inductions were being ordered.
- The electromagnetic relay, NSN 7H H 5845-00-790-4885, had two RFI units and ten NRFI units on hand (all F condition). Demand for this NSN was only 0.02 per quarter; therefore the NRFI units weren't being inducted.

From this initial attempt to gather information, several lessons were learned:

- NRFI DLRs are presently only inducted for repair when they are needed to replenish stock or support fleet operations. If there is sufficient RFI stock, the failed units are stored in F condition at the DSP until needed. An additional element was added to the sample selection criteria as a result of this finding: there must have been at least one repair induction during the past two years.
- The MRIL doesn't list the DOP in all cases. The Maintenance/Overhaul Designator (MOD) code determines whether the MRIL shows direct shipment of carcasses to the DOP or to a DSP where the NRFI units are held until needed. MOD code 1 results in the actual DOP name and address appearing in the MRIL, while MOD code 3 causes the DSP name and address to appear in the MRIL [Ref. 12: p. 3]. The MOD code is Data Element Number (DEN[5]) B075D in the UICP data base and the SPCC item managers can change the MOD code for each DLR as required [Ref. 5: p. U-3].

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5 A DEN is a code used to identify the location of inventory related information in UICP files.

For DOPs close to a NSC, the NSC is the DSP. The DSP sends the necessary TIRs to SPCC and stores the material until SPCC schedules a repair induction and the DOP inducts the item.

For DOPs not close to a NSC, such as Naval Weapons Support Center (NWSC) Crane, IN, the DOP Supply Department acts as the DSP, sending TIRs to SPCC and storing the carcasses until needed.

For this study SPCC's Repairables Support Department (code 035) had to do a WSF query to identify the DOP for the items with MOD code 3.

- The research on the three items having NSC Puget Sound as the DSP in the MRIL provided a clear picture of the flow of information and material in the organic repair process. This information and material flow is illustrated in Figure 4 [Ref. 26: p. 16]. In Figure 4, the numbers in parentheses represent the sequence of events in the repair cycle.
- Repair turnaround time (RTAT), as collected and maintained by SPCC, is not a good estimate of the mean repair service rate. The mean repair service rate, as discussed in Chapter III, is required in the first computational step of the proposed model and includes only the time an item actually spends on the bench being repaired. RTAT, on the other hand, has four different time segments: [Ref. 26: p. 36]
    - DOP material receipt -- The time from when the DSP ships the carcass and sends the M condition TIR until the carcass is received at the DOP.
    - DOP induction -- The time from DOP receipt of carcasses until the repair start date. Although Rodwell (see Ref. 26) states in his thesis that the TIR changing the material condition code from F to M should be sent when the actual repair begins, the M condition TIR is being sent when the DSP ships the material to the DOP [Ref. 24].
    - DOP repair in process -- The time it takes to repair the NRFI material.
    - RFI receipt time -- The time from completion of the repair until the item is reported in A condition via TIR. This includes time spent in preservation and packing after the repair is complete, transportation time to the DSP, storage processing time at the DSP, and TIR preparation time at the DSP.

As described above, RTAT includes many different segments of time other than repair time; therefore, RTAT can't be used as an estimate of the average repair rate variable in the proposed model. The unsuitability of RTAT is discussed in more detail later in this chapter.

Referring back to Table 4, the MRIL listed ALCO Power Company as the DOP for the two diesel engines and the diesel engine block. ALCO Power was, in fact, the DOP. After several calls, Mr. Steve Farrow of ALCO's contracts department was asked to provide:

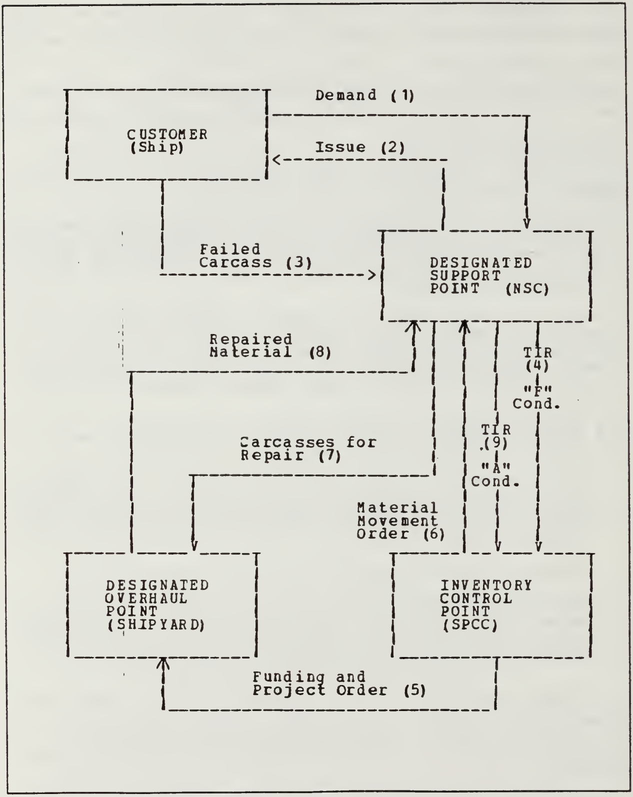

Figure 4. Organic Repair Process for DLRs

- The number of repair stations or channels used to repair each of the three DLRs.
- The average service time or the actual service times for repairs over the past two years.

ALCO Power was unable or unwilling to provide any information on the three items, but several things were learned:

- Commercial DOPs often work with part numbers and can't identify an item by its NSN. ALCO was provided the NSN, part number, and description of the three items.
- Commercial DOPs that compete for repair business may be unwilling to provide actual service times to Navy personnel for fear that the information will be used against them in contract negotiations. In the author's opinion, this was the case with ALCO Power.
- Some commercial DOPs don't have information systems set up to easily record and retrieve actual service times. ALCO Power could easily provide standard labor hours and rates used to charge the Navy for work, but not actual service man-hours.
- A better method was needed to penetrate commercial DOP organizations to get the information needed for this study.

E. RESOLUTION OF DIFFICULTIES AND FINAL SAMPLE SELECTION

Summarizing the lessons learned from the last section, three issues require further discussion:

- Identifying DLRs that had been inducted for repair at least once in the past two years was necessary; therefore, a procedure to accomplish this was needed.
- Identifying the DOP for each of the sample DLRs was also required. A procedure for identifying the DOP needed to be developed.
- Establishing points of contact at SPCC who could help gather data for each of the sample DLRs from the DOPs was necessary.

The solutions to these three issues are discussed in the following sections.

1. Identifying DLRs That Are Being Repaired

Out of the 40 NSNs initially selected, SPCC's Repairables Support Department (code 03512) was given 12 items that were selected at random. SPCC did a manual review of each NSN against the Transaction History File (THF) and determined that 6 of the 12 NSNs had no repair history for the past two years. So, to complete the sample, SPCC's Repairables Support Department (code 03512) randomly selected six other DLRs using the selection criteria discussed in the beginning of this chapter. The sample of DLRs selected for this study are presented in Tables 6 and 7.

Table 6. SAMPLE DLRS USED IN THIS STUDY

COG, MCC, and NSN	NSN Selected By:	Quarterly Demand Forecast	RTAT	RSR	DOP
7H H 5840-00-004-2754	Author	3.92	1.87	1.0	NSY Long Beach
7H H 1290-00-177-9946	SPCC	3.79	4.15	1.0	Ocean Technology, Burbank, CA
7H H 1285-00-182-3756	SPCC	3.57	3.66	1.0	Ocean Technology, Burbank, CA
7H H 1285-00-187-6676	Author	0.03	5.86	1.0	NWSC Crane, IN
7H H 5895-00-494-0145	SPCC	0.11	0.30	0.99	GTE, Mountain View, CA
7H H 6110-00-889-8110	Author	3.65	0.56	0.99	NSY Long Beach
7H H 1440-01-029-1741	Author	4.29	0.69	1.0	NWS Seal Beach, CA
7H H 1440-01-029-2581	Author	2.09	0.42	1.0	NWS Seal Beach, CA
7H H 2040-01-032-9059	SPCC	0.02	2.70	0.99	Sperry Marine, Charlottesville, VA
7H H 2040-01-037-3691	SPCC	2.51	4.0	0.99	Koll Morgen, N. Hampton, MA
7H E 6605-01-112-6484	Author	30.59	1.24	1.0	Rockwell, Anaheim, CA and Aerospace Guidance and Meteorological Center (AGMC), Newark A. F. Station, OH

Table 7. SAMPLE DLRS USED IN THIS STUDY (CONTINUED)

COG, MCC, and NSN	NSN Selected By:	Quarterly Demand Forecast	RTAT	RSR	DOP
7G H 5820-01-113-7212	SPCC	1.24	1.04	1.0	Naval Electronics System Engineering Center (NESEC) San Diego, CA

For future studies having a large number of DLRs, a screening program must be developed to determine which DLRs have been actively repaired in the past two years. As discussed in Chapter I, an expanded study using a simulation would use THF data on magnetic tape or disk. The THF data must be screened by document identifier to identify different records as demands, surveys, and repair inductions. Repair inductions can be identified by TIRs having a Document Identifier (DI) of D4_, D6_, D8C, Z3C, or Z3D and material condition code M. The DI indicates a material status change and the M condition code means that a repair induction has occurred. These five DIs are defined as follows:

- D4_ -- Receipt transaction that notifies the ICP that a stock point has received material from procurement, repair, or other specified source [Ref. 27: p. 2-4].
- D6_ -- Receipt transaction that notifies the ICP that a stock point has received material from other than procurement sources. The source may be a redistribution order or material turned-in to store [Ref. 27: p. 2-5].
- D8C -- Inventory adjustment transaction that increases an activity's on hand balance of material having the condition code specified in position 71 of an item's record [Ref. 27: p. 4-5].
- Z3C -- A repair in process time observation from a Navy TIR reporting activity that is outside filter limits [Ref. 27: p. 5-92]. Transactions having this DI are used to correct erroneous TIR information and are input after the IM reviews and corrects the erroneous transactions on a TIR processing error list.
- Z3D -- A repair turnaround time observation from a Navy non-TIR reporting activity or commercial repair activity that is outside filter limits [Ref. 27: p. 5-92]. Use of the Z3D DI is the same as the Z3C.

Any NSN having a DI of D4_, D6_, D8C, Z3C, or Z3D has had repair activity in the past two years since the THF only contains two years of transactions [Ref. 28].

Figure 5 shows a sample THF record. Each line on the THF printout in Figure 5 represents one transaction. The information listed under the first column labeled, "DIC," is the document identifier code. The second column, "4-6," contains a routing identifier or identification code of the activity that submitted the TIR. Other important columns and their meanings are:

- NIIN -- National item identification code. The NIIN uniquely identifies the material and consists of the last nine digits of the NSN.
- Doc Number -- Document number. The document number consists of a six digit Unit Identification Code (UIC), a four-digit julian date, and a serial number. Referring to Figure 5, the first five digits in this column are not part of the document number, but represent the quantity. The UIC, which identifies the activity initiating this transaction, is represented by the next six digits. For example, "N97456," is the UIC for the first transaction listed in Figure 5. The julian date and serial number follow the UIC.
- C -- The column labeled with a "C" has the material condition code listed beneath it.
- Tra Date -- The transaction date is listed in this column. This is the date that the transaction was received by SPCC. This is the starting date used in calculating RTAT.

2. Identifying the DOP

For this thesis, SPCC's Repairables Support Department (code 03512) did a manual retrieval of the data from the Repairables Master File (RMF) to identify the DOPs listed in Tables 6 and 7. For future studies that have a large number of DLRs, the DENs listed in Table 8 can be retrieved and stored on magnetic tape for each DLR. These DENs can then be used to determine the actual DOP using a screening program with logic similar to that presented in Figure 6.

DATE 89223 BO4UH1L THF INTERROGATES

DIC	4-6	M S	FSC	NIIN	SMICUI	DDC NUMBER	SUP AD	COG		ADV	ACT	P	C	M	TRA DATE	76-80	81-86	DATE PRDC
D9C	JGC		1290	001779946	EA	00001N9745691920058	YC2X	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920059	YC2X	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920060	YC2X	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920063	YC2U	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920064	YC2U	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920065	YC2U	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
D9C	JGC		1290	001779946	EA	00001N9745691920066	YC2U	7A 7H	DA	AM	QQQ	A	F		220	H M3		9221
DZA	JGC		1290	001779946	EA	000000		7H	20	403000	QQQ	A	H		220	HUPRD		9221
DZA	JGC		1290	001779946	EA	000024		7H	20	403000	QQQ	A	M		220	HUPRD		9221
D8C	JGC		1290	001779946	EA	00001N9745691920041	YC2W	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920042	YC2W	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920043	YC2W	7A 7H	DA	AF	QQQ	A	M		22D	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920044	YC2W	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920045	YC2W	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920046	YC2W	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920047	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920048	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920049	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920050	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920051	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221
D8C	JGC		1290	001779946	EA	00001N9745691920052	YC2Y	7A 7H	DA	AF	QQQ	A	M		220	H D3		9221

Figure 5. Transaction History File (THF) Record

Table 8. DATA ELEMENT NUMBERS (DEN) TO IDENTIFY THE DOP

DEN	DEN Name	DEN Description
F016	Designated Collection/Overhaul Point	Provides the UIC for organic DOPs or the CAGE for commercial DOPs.
F016A	DOP Availability Schedule Date	The date that the DOP will have the capability to repair this NSN.
F016D	Availability/Phaseout/Collection Point Indicator	1 = The UIC or CAGE in DEN F016 is a collection point. 0 or 2 = the UIC/CAGE in DEN F016 is the DOP.
F067B	Repair Contract Number	Provides the current repair contract number if there is one. The contract number can be useful when talking with commercial DOP personnel.
F146	Deletion Indicator	x = The UIC or CAGE in DEN F016 is no longer a DOP.

The Commercial And Government Entity (CAGE) code uniquely identifies a commercial activity that does business with the government. CAGE codes are found in the Navy's Cataloging Handbook (H4-1) microfiche.

3. SPCC Points of Contact to Help Gather DOP Data

SPCC's Repairables Support Department (code 035) has an organic repair supervisor and a commercial repair supervisor in code 03533. These repair supervisors are responsible for liaison with the IMs and liaison between SPCC and the DOPs. Part of their responsibility includes running a semiannual repair conference where DOP representatives: [Ref. 28]

- Are given an SPCC estimate of the number of carcasses to expect for the next six months.
- Negotiate repair quantity in relation to DOP repair capacity.
- Confirm repair prices, RSR forecasts, and RTAT forecasts.
- Discuss any difficulties that need to be resolved.

Because they have frequent contact with DOP personnel, code 03533 was able to provide points of contact (POCs) and telephone numbers for each DOP in the sample. In all cases, the POCs at the DOPs were willing to cooperate with this research.

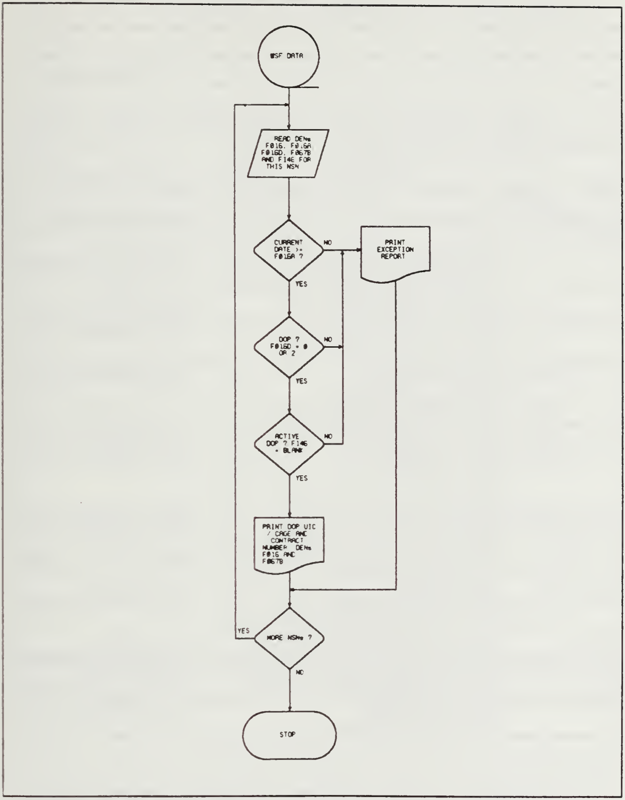

Figure 6. Logic Used to Find the DOP

Another valuable source of DOP information is the SPCC Repairables Management Field Representative (RMFR). Table 9 provides the current list of SPCC RMFRs. These nine representatives each have an assigned territory and they make frequent trips to all DOPs (organic and commercial) in their territory. [Ref. 29] Since they make site visits, the RMFRs have POCs in the DOP who can provide detailed information on repair processes and times.

Table 9. SPCC REPAIRABLES MANAGEMENT FIELD REPRESENTATIVES (RMFR)

SPCC RMFR Name	RMFR Location	Telephone Number
Jim Cain	Naval Ordnance Station (NOS) Louisville, KY 40214-5001 Attn: SPCC RMFR MDS 47	A/V 989-5838 Comm: (502) 364-5838
Bill Clymer	NWSC Crane, IN 47522-5000 Attn: SPCC RMFR Code 70	A/V 482-1874 Comm: (812) 854-1874
Jim Caton	NSY Norfolk Portsmouth, VA 23709-5000 Attn: SPCC RMFR Code 205	A/V 961-7769 Comm: (804) 396-7769
Bob Clement	NESEC San Diego P. O. Box 80337 San Diego, CA 92138-5038 Attn: SPCC RMFR Code 03	A/V 524-2861 Comm: (619) 524-2861
Stan Chastain	NWSC Crane, IN 47522-5000 Attn: SPCC RMFR Code 803	A/V 482-3759 Comm: (812) 854-3759
Chobby Betts	NSC San Diego 937 N. Harbor Dr. San Diego, CA 92132-5044 Attn: SPCC RMFR Code 300	A/V 526-5125 Comm: (619) 556-5125
Chuck Bunting	NSC Norfolk, VA 23512-5000 Attn: SPCC RMFR Code 800D	A/V 565-2528 Comm: (804) 445-2528
Don Monise	Naval Undersea Warfare Engineering Sta. Keyport, WA 98345-0580 Attn: SPCC RMFR Code 11	A/V 744-2925 Comm: (206) 396-2925
Vince Spagnola	Navy Electronics Maintenance Center 1609A Diamond Springs Rd. Virginia Beach, VA 23455-5000 Attn: SPCC RMFR Code 340A	A/V 564-3016 Comm: (804) 444-3016
Vacant	NSY Long Beach, CA 90822-5099 Attn: SPCC RMFR Code 224	A/V 360-7313 Comm: (213) 547-7313
Vacant	NWS Seal Beach, CA 90740-5000 Attn: SPCC RMFR Code 01	A/V 873-7396 Comm: (213) 594-7396
Vacant	NSY Mare Island Vallejo, CA 94592 Attn: SPCC RMFR Code 219	A/V 253-2522 Comm: (707) 646-2522

For this study, a combination of DOP representatives and RMFRs were used to gather data from the DOPs. These POCs are listed in Table 10 for each DLR in the sample.

While data from the DOPs can be collected, it took a month to gather the information for 12 sample items. Expanding this study to more items will require an automated or semi-automated data collection process. A suggested process is discussed later in this chapter.

Table 10. DOP POINTS OF CONTACT (POC) FOR SAMPLE NSNS

NSN	DOP	POC Name	Telephone Number
7H H 5840-00-004-2754	NSY Long Beach	Chobby Betts (RMFR)	A/V 526-5125
7H H 1290-00-177-9946	Ocean Technology, Burbank, CA	Wayne Drury	(213) 849-7111 (x314)
7H H 1285-00-182-3756	Ocean Technology, Burbank, CA	Wayne Drury	(213) 849-7111 (x314)
7H H 1285-00-187-6676	NWSC Crane, IN	Bill Clymer (RMFR) / Terrell Houchins	A/V 482-1874
7H H 5895-00-494-0145	GTE, Mountain View, CA	Lou Cardarelli	(415) 966-4065
7H H 6110-00-889-8110	NSY Long Beach	Chobby Betts (RMFR)	A/V 526-5125
7H H 1440-01-029-1741	NWS Seal Beach, CA	Chobby Betts (RMFR)	A/V 526-5125
7H H 1440-01-029-2581	NWS Seal Beach, CA	Chobby Betts (RMFR)	A/V 526-5125
7H H 2040-01-032-9059	Sperry Marine, Charlottesville, VA	Sam Grimsby	(804) 974-2362
7H H 2040-01-037-3691	Koll Morgen, N. Hampton, MA	Tony Tallman	(413) 586-2330 (x2497)
7H E 6605-01-112-6484	Rockwell, Anaheim, CA	Chobby Betts (RMFR)	A/V 526-5125
7H E 6605-01-112-6484	AGMC, Newark Air Force Station, OH	Ned Phelps (Symbol MASW)	A/V 346-7340
7G H 5820-01-113-7212	NESEC San Diego, CA	Vern Brumley (Code 315)	A/V 524-2869

F. SPCC LEVELS MODEL DATA AND EMULATION PROGRAM RESULTS

This section discusses the variables needed to calculate the reorder quantity ($\hat{Q}$), reorder level ($\hat{R}$), repair quantity ($\hat{Q}_2$), and repair level ($\hat{R}_2$). The data collection methods are discussed and the output from the levels emulation program in Appendix A is compared to the actual SPCC levels program output for the 12 sample items.

1. Variables Required for the Current SPCC Levels Model (D01)

The CARES data base was the initial source of variable data for this study, but was rejected after a careful analysis of the FMSO UICP Levels Program Functional Description (FMSO Document Number FD-D01). The CARES program and the UICP levels program use different data element numbers (DENs) for demand (D) and regenerations (G). CARES uses DEN B074 for D and B074A for G, while levels uses B023D and B023F for D and G, respectively. Although FMSO believes that these DENs contained equivalent numbers, the potential for differences seems high in a system as complex as the UICP [Ref. 30]. Table 11 shows a comparison of the values of the DENs used for D and G in CARES and in UICP. Although the comparison is for only 12 NSNs, the systematic values are evidence that the DENs are not identical.

After further investigation, the differences between B074 and B023D, as well as the differences between B074A and B023F, were caused by the way the storage area for each variable is defined by FMSO. [Ref. 6] In the case of the demand values, the B074 storage field carries only two decimal places, while the B023D storage field carries eight decimal places. In the regeneration case, B074A's storage field carries two decimal places, while B023F's storage field carries only one decimal place.

When FMSO calculates DENs B074, B074A, B023D, and B023F in its levels program, these variables are defined as real numbers; therefore, for the computation of these DEN values and for the computation of the rest of the levels values, B074, B074A, B023D, and B023F have full floating point decimal fields. After all levels computations are complete, the values for B074, B074A, B023D, and B023F are stored in fields having a limited number of decimal places, and therefore, truncation occurs. The truncation doesn't significantly effect the accuracy of the B023D values, however, because the storage field for B023D has eight decimal places.

Table 11. COMPARISON OF CARES AND LEVELS PROGRAM DEMAND AND REGENERATION DATA

	Demand (D)		Regenerations (G)	
COG, MCC, and NSN	B074 (CARES)	B023D (Levels)	B074A (CARES)	B023F (Levels)
7H H 5840-00-004-2754	3.92	3.92674	3.92	3.90
7H H 1290-00-177-9946	3.79	3.79889	3.64	3.60
7H H 1285-00-182-3756	3.57	3.57152	3.57	3.50
7H H 1285-00-187-6676	0.03	0.03195	0.02	0.00
7H H 5895-00-494-0145	0.11	0.11059	0.10	0.10
7H H 6110-00-889-8110	3.65	3.656	3.43	3.40
7H H 1440-01-029-1741	4.29	4.29511	1.93	1.90
7H H 1440-01-029-2581	2.09	2.09849	2.01	2.00
7H H 2040-01-032-9059	0.02	0.02488	0.02	0.00
7H H 2040-01-037-3691	2.51	2.52	2.39	2.30
7H E 6605-01-112-6484	30.59	30.59998	30.59	30.50
7G H 5820-01-113-7212	1.24	1.25	1.08	1.00

As the reader will see in the next section, using the truncated values stored for DENs B023F, B074, and B074A in the emulation program caused some differences between the emulation program results and the actual SPCC program results.

Since the DENs used in levels, B023D and B023F, were used in the emulation program listed in Appendix A, a standard record format such as CARES couldn't be used for input to the emulation program. Instead, a list of required DENs was assembled from a review of FMSO's Levels Program Functional Description (FMSO Document Number FD-D01). As stated in the first part of this chapter, the DENs required for the emulation program were broken into four categories:

- System constants -- Those input elements that are constant for all NSNs.
- Four digit COG constants -- Those input elements that are constant for all NSNs having the same four-digit COG.
- Unique input variables -- Those input elements that vary for each NSN.
- Comparison data -- Those data elements used to compare the emulation program results with actual SPCC results.

All of the data elements in the four categories were requested from SPCC by DEN. The DENs requested for the system constants, four-digit COG constants, and unique input variables are shown in Tables 12 through 14. These tables also give the corresponding FORTRAN program variable names which are used in the emulation program in Appendix A.

Table 12. SYSTEM CONSTANTS

DEN	Description	Variable Name In Program	Current Value
None	Annual holding cost	H	0.21
None	Maximum number of quarters of safety stock	MQTRSL	20
C008C	Military Essentiality Code (MEC)	E	0.50
V016	Administrative cost to repair one item	AC	$ 730.00
V039	Repair review cycle time	RRCT	0
V043	Procurement ordering cost	A1	$ 1730.00

In Table 12, the annual holding cost actually equals the sum of the obsolescence rate (DEN B057), the time preference rate (DEN V108), and storage rate (0.01) [Ref. 5: p. O-23]. Also, the maximum number of quarters of safety stock is an input parameter on the control card image used to run the levels program. The current values are all initialized at the beginning of the emulation program in Appendix A.

Table 13. FOUR DIGIT COG CONSTANTS

DEN	Description	Variable Name In Program
V022	Minimum allowable risk	RMIN
V028	Probability Break Point	PBP
V102	Maximum Allowable Risk	RMAX
V104	Shortage cost	LAMBDA
V295	Reorder level constraint value	RLCONS

The constants in Table 13 depend on the NSN's four-digit COG symbol. These values are built into the emulation program in the COGVAL subroutine.

There are several misleading titles for the variables in Table 14. The values stored in the DEN B023D field, gross system demand - end of lead time, are equivalent to the quarterly demand forecast values (DEN B074). The values stored in the DEN B023F field, system RFI regenerations - end of lead time, are equivalent to the quarterly regenerations forecast values (DEN B074A). Finally, discount quantity (DEN B061) is a misleading title, because the B061 value is not used to specify a price break quantity, but, instead, is used to specify a minimum buy quantity in the UICP levels program.

There were no difficulties collecting the data elements for the current levels setting model beyond deciding which variables were necessary. The actual data collected for the 12 DLRs is listed by DEN in Tables 15 and 16.

Table 14. UNIQUE INPUT VARIABLES NEEDED FOR EACH NSN

DEN	Description	Variable Name In Program
A003	Number of policy receivers	NRPR
A023B	Requisition frequency average	RF
B019A	Procurement problem variance	PVAR
B020	System reorder level low limit quantity (numeric stocking objective)	NSO
B023C	Gross system demand during lead time	DLT
B023D	Gross system demand - end of lead time (units/qtr)	D
B023E	System RFI regenerations during lead time	GLT
B023F	System RFI regenerations -- end of lead time (units/qtr)	G
B023G	RFI regenerations during repair problem turn around time	GRTAT
B023H	Demand during repair problem turn around time	DRTAT
B055	Replacement cost	C1
B055A	Repair cost	C2
B058	Manufacturer's setup cost	A1
B058A	Repair setup cost	A2
B061	Discount quantity	DSCNTQ
B070	Life of type quantity	LOT
B074	Quarterly demand forecast	DBAR
C003	First two digits of the four-digit COG	COG1
C003W	Second two digits of the four-digit COG	COG2
C028	Shelf life code	SLC
D120	Level of authority code -- Secondary Inventory Control Activity (SICA)	AUTHLV
D125N	Nonconsumable item material support code	NIMSC
E089	Acquisition advice code	AAC

Table 15. SPCC LEVELS MODEL INPUT DATA

	National Item Identification Number (NIIN)					
DEN	00-004-2754	00-177-9946	00-182-3756	00-187-6676	00-494-0145	00-889-8110
A003	5	2	3	0	0	3
A023B	3.92674	3.79413	3.57152	.03195	.11059	3.656
A019A	249.31392	327.6897	356.06592	0.43832	4.35817	169.91716
B020	1	1	1	1	0	1
B023C	43.78323	40.04028	38.57242	0.28947	0.8228	34.22017
B023D	3.92674	3.79889	3.57152	0.03195	0.11059	3.656
B023E	43.7	38.4	38.5	0.2	0.7	32.1
B023F	3.9	3.6	3.5	0	0.1	3.4
B023G	8.0	15.8	13.7	0.1	0	2.5
B023H	7.3	15.7	13.0	0.1	0	2.0
B055	4637.00	5473.00	445.00	683.38	22685.79	992.00
B055A	462.00	295.00	501.07	500.00	8400.00	441.00
B058	0	0	0	0	0	0
B058A	0	0	0	0	0	0
B061	0	0	0	0	0	0
B070	0	0	0	0	0	0
B074	3.92	3.79	3.57	0.03	0.11	3.65
C003	7H	7H	7H	7H	7H	7H
C003W	4D	3A	3A	3F	3C	4D
C028	0	0	0	0	0	0
D120	22	22	22	22	22	22
D125N	V	V	V	V	V	V
E089	C	C	C	C	C	C

Table 16. SPCC LEVELS MODEL INPUT DATA (CONTINUED)

	National Item Identification Number (NIIN)					
DEN	01-029-1741	01-029-2581	01-032-9059	01-037-3691	01-112-6484	01-113-7212
A003	5	3	0	2	0	0
A023B	4.27768	2.00876	0.02488	2.52	30.59998	1.00
A019A	189.60701	81.68222	0.32954	1020.13599	1414.23926	17.14398
B020	1	1	1	1	1	0
B023C	47.24622	19.64189	0.19907	45.36002	373.93188	9,81251
B023D	4.29511	2.09849	0.02488	2.52	30.59998	1.25
B023E	21.2	18.8	0.1	43.0	373.9	8.5
B023F	1.9	2.0	0	2.3	30.5	1.0
B023G	1.7	1.2	0	10.0	43.7	1.3
B023H	2.9	0.8	0	10.0	37.9	1.3
B055	5425.00	579.21	2256.00	14434.52	498852.96	638.00
B055A	2957.60	445.00	1161.00	2500.00	45524.50	238.00
B058	0	0	0	0	0	0
B058A	0	0	0	0	0	0
B061	0	0	0	0	8	0
B070	0	0	0	0	0	0
B074	4.29	2.09	0.02	2.51	30.59	1.24
C003	7H	7H	7H	7H	7H	7G
C003W	4A	4B	3F	3E	3A	3B
C028	0	0	0	0	0	0
D120	22	22	22	22	22	22
D125N	V	V	V	V	V	V
E089	V	C	C	C	C	C

2. Emulation Program Results

Tables 17 and 18 show a comparison of the initial output from the emulation program in Appendix A with the actual UICP levels program output as recorded in the UICP files.

Table 17. EMULATION PROGRAM RESULTS VS. ACTUAL SPCC RESULTS

COG, MCC, and NSN	Emulation Program $\hat{R}$	SPCC $\hat{R}$	Emulation Program $\hat{Q}$	SPCC $\hat{Q}$
7H H 5840-00-004-2754	25	25	1	1
7H H 1290-00-177-9946	32	33	2	2
7H H 1285-00-182-3756	30	30	1	1
7H H 1285-00-187-6676	1	1	1	1
7H H 5895-00-494-0145	1	1	1	1
7H H 6110-00-889-8110	19	19	3	3
7H H 1440-01-029-1741	32	32	6	6
7H H 1440-01-029-2581	6	6	2	2
7H H 2040-01-032-9059	1	1	1	1
7H H 2040-01-037-3691	21	21	2	1
7H E 6605-01-112-6484	54	54	1	1
7G H 5820-01-113-7212	5	6	3	2

As noted in the last section, when the FMSO levels program stores the values for DENs B074, B074A, B023D, and B023F, truncation occurs. Since the emulation program uses these truncated values, some rounding errors occur. The differences between the emulation program levels and the SPCC computed levels noted in Tables 17 and 18 result from rounding errors in the emulation program.

The rounding problem was resolved by computing the B023F and B074A values instead of using the truncated values. Since the DEN for quarterly demand (D), B023D, has a sufficient number of decimal places to prevent rounding errors, this value was not recomputed. The B074 value was set equal to the B023D value since they are computed from the same formula.

Table 18. EMULATION PROGRAM RESULTS VS. ACTUAL SPCC RESULTS (CONTINUED)

COG, MCC, and NSN	Emulation Program $\hat{R}_2$	SPCC $\hat{R}_2$	Emulation Program $\hat{Q}_2$	SPCC $\hat{Q}_2$
7H H 5840-00-004-2754	25	25	16	16
7H H 1290-00-177-9946	31	32	19	19
7H H 1285-00-182-3756	30	30	14	15
7H H 1285-00-187-6676	0	1	1	2
7H H 5895-00-494-0145	0	1	1	1
7H H 6110-00-889-8110	17	17	15	15
7H H 1440-01-029-1741	8	8	5	5
7H H 1440-01-029-2581	5	5	12	12
7H H 2040-01-032-9059	0	1	1	1
7H H 2040-01-037-3691	19	19	6	6
7H E 6605-01-112-6484	49	49	5	5
7G H 5820-01-113-7212	4	5	11	12

That is: [Ref. 5: pp. O-7 O-14 O-25]

D = B074 = B023D = $D_1 + D_2$;

where:

D_1 = DEN B022 or system recurring demand average;

D_2 = DEN B022A or system recurring demand average from overhaul.

The regeneration values, DENs B074A and B023F, are computed using the same formula: [Ref. 5: pp. O-9 O-15 O-24]

G = B074A = B023F = RSR × CR + D_2(1 − WOR);

where:

RSR = DEN F009 or repair survival rate forecast;

CR = DEN B022B or forecasted number of carcasses returned per quarter;

WOR = DEN F007 or wear out rate forecast.

The RSR is defined as the percentage of items inducted for repair that can be expected to be returned to RFI condition [Ref. 5: p. 3-16]. The WOR is defined as the percentage of items inducted for repair that can be expected to become NRFI [Ref. 5: p. 3-19].

Although it appears that RSR = (1 − WOR), this is not the case. The computation of RSR includes surveys at the depot level only [Ref. 5: p. 3-16], while the WOR computation includes both depot level surveys and below depot surveys (i.e., from intermediate and organizational maintenance levels) [Ref. 5: p. 3-19].

The CR is a forecast of the number of carcasses per quarter expected to be received from Navy activities, excluding ships in overhaul. [Ref. 5 : p. M-4] CR is computed as $D_1 \times (1 - \text{WOR})/\text{RSR}$. Notice that if this formula for CR is substituted into the equation for regenerations (G) above, G becomes:

$$G = D_1(1 - \text{WOR}) + D_2(1 - \text{WOR})$$

$$= (D_1 + D_2)(1 - \text{WOR})$$

$$= D(1 - \text{WOR}).$$

Reducing the equation for G is significant because it reduces the number of DENs for which data must be collected. In this case, the only additional DEN needed to calculate G is WOR (DEN F007) since the value for D (DEN B023D) is already being used in the emulation program.

The WOR values collected and the newly computed G values for each of the 12 sample DLRs are listed in Table 19. The values for G listed in Table 19 were computed manually. For future studies, the emulation program in Appendix A requires modification so that the WOR values can be input to the program and then used to calculate the G values.

Also note that the WOR values for 3 of the 12 sample DLRs exceed ten percent. Recall that the CARES data base was used to select the sample DLRs. Since the CARES data base only contains RSR values, the assumption was made that a high RSR value equated to low attrition. The WORs for at least 3 of the 12 sample DLRs indicate that the items should not have been classified as low attrition DLRs. Future studies should include WOR as part of the sample selection criteria.

When the G values listed in Table 19 were used as input to the emulation program, the emulation program levels matched the UICP program levels exactly, except

for the reorder level ($\hat{R}$) and repair level ($\hat{R}_2$) for NSN 1440-01-029-2581. The UICP program output was $\hat{R} = 6$ and $\hat{R}_2 = 5$, while the emulation program output was $\hat{R} = 7$ and $\hat{R}_2 = 6$.

Table 19. WEAR OUT RATE (WOR) AND CALCULATED REGENERATION (G) VALUES FOR THE SAMPLE DLRS

COG, MCC, and NSN	WOR	G
7H H 5840-00-004-2754	0.00	3.92674
7H H 1290-00-177-9946	0.04	3.6469344
7H H 1285-00-182-3756	0.00	3.57152
7H H 1285-00-187-6676	0.08	0.029394
7H H 5895-00-494-0145	0.09	0.1006369
7H H 6110-00-889-8110	0.06	3.43664
7H H 1440-01-029-1741	0.55	1.9327995
7H H 1440-01-029-2581	0.04	2.0145504
7H H 2040-01-032-9059	0.13	0.0216456
7H H 2040-01-037-3691	0.05	2.394
7H E 6605-01-112-6484	0.00	30.59998
7G H 5820-01-113-7212	0.13	1.0875

After exhaustive research by the author, an error in the UICP levels program was discovered. The emulation program result is correct. The following paragraphs explain the research done to find the UICP program error and then describe the error.

From Chapter II, the basic repair level (R_2) formula was:

$$R_2 = DT_2 + R - Z$$

Since the value of R_2 depends on the value of the basic reorder level (R), and both $\dot{R}$ and R_2 had quantity differences of equal direction and magnitude, the author suspected an error in the computation of R in the emulation program.

When a complete review of the UICP program specifications proved that the emulation program logic was correct, the levels for the discrepant item were computed manually. Since the manual computations matched the emulation program results, a copy of the UICP levels program was obtained from FMSO.

Manually performing the UICP program's steps using the data for NSN 1440-01-029-2581 produced results identical to those stored in SPCC's files (i.e., $\hat{R} = 6$ and $\hat{R}_2 = 5$).

Since the normal distribution was used to compute the reorder level values, the normal distribution table in the UICP program was reviewed against the normal distribution table in Reference 11. The table in the UICP program consists of 50 values. The first value in the UICP program's table, "RISKTB (1) = 0.46017220," corresponds to a normal deviate value (z) = 0.1, and is the value of the area under the normal curve and to the right of z = 0.1 (i.e., 0.46017220). Note that the area under the normal curve and to the right of z is stockout risk.

The fourth table value (i.e., RISKTB (4) = 0.33457830) in the UICP table was erroneous. This value should have been RISKTB (4) = 0.34457830. This incorrect value associated with z = 0.4 produced the erroneous levels computations at SPCC for NSN 1440-01-029-2581. FMSO was informed of the UICP program error by the author and FMSO confirmed that the error in the UICP program was genuine [Ref. 31].

G. PROPOSED LEVELS MODEL DATA

By reviewing the formulas presented in Chapter III, one can see that data for the following parameters needs to be collected to calculate the target minimum population size (K_i), incremental reorder point quantity (R_i), and reorder quantity (Q_i):

- For K_i:

  U -- The number of installed units of each DLR.

  c -- The number of repair channels or stations at the repair facility.

  α -- The average failure rate of each DLR.

  μ -- The average repair or service rate per repair channel.

- For R_i:

  D -- Quarterly demand forecast for each DLR.

  G -- Quarterly regenerations forecast for each DLR.

  I -- Inventory holding cost rate;

  C -- Procurement unit cost for each DLR;

  C_2 -- Repair unit cost for each DLR;

  λ -- Shortage cost per requisition backordered;

  E -- Military essentiality for each DLR;

  F -- Quarterly requisition frequency forecast (i.e., requisitions per quarter.

- For Q_i:

  A -- Administrative ordering cost.

  D -- Quarterly demand forecast for each DLR.

  G -- Quarterly regenerations forecast for each DLR.

  I -- Inventory holding cost rate.

  C -- Unit cost of each DLR.

The parameter values associated with R_i and Q_i are readily available from SPCC's UICP files since they are used in the current model. Refer to Tables 15 and 16 for these values. The availability of data for the K_i variables is discussed in the following sections.

1. Number Of Installed Units (U)

The data for the number of installed units is readily available from the WSF by having SPCC's Systems Services Division (code 04232) run an A10 application program. A sample A10 printout is shown in Figure 7. The A10 program output can be provided on magnetic tape.

Although the A10 printout appears complicated, it's really very simple to interpret. [Ref. 32] Referring to Figure 7, the top line beginning with "Z0423TW" provides the following information:

- Z0423TW -- A code that identifies the requestor of the A10 run.
- 008898110 -- The National Item Identification Number (NIIN), which is the last nine digits of the NSN.
- 89286 -- The julian date of the run. In this case, 89 is 1989 and 286 is 13 October.
- 21:09 -- The time of the A10 run.

The next two lines, beginning with, "C3/7H," and "F27/0000000.0410," provide identification data for this NIIN (i.e., 00-889-8110). The characters before the slash (/) represent the DEN and the characters after the slash represent the data stored in that DEN. For example, the second line in Figure 7 begins with, "C3/7H." The C3 means DEN C003 (the cognizance symbol) and the 7H is the value of this DEN for NIIN 00-889-8110.

The next six lines, the fourth through ninth lines in Figure 7, present information for one equipment into which NIIN 00-889-8110 is installed. The equipment is uniquely identified by its Allowance Parts List (APL) number. In Figure 7, the fourth line begins with the APL number (i.e., D9 57039655). Here, "D9" represents DEN D009 and "57039655" represents the APL number. This APL number identifies the equipment

```
Z0423TN    008898110                                           89286        21:09     PAGE    1

C3/7H C3D/   C3A/H C3B/   C42/6110 C4/REGULATOR,VOLTAGE   B53/0001100.00 C5/EA
F27/0000000.0410 E106/G DMD/0000003.65 D13C/L Y002/MDF

D9/57039655   D29/EP D11/ 000002 D13/4L C7/0001 C7A/000 C7B/
D31/AA D44/X E1/AN/SPS-40B, RADAR SET
NHA: NX5071     ZB 00001 N0581A     ZC 00001 N41922     ZB 00001 RX5104     ZB 00001 R01711     ZD 00001
NHA: R04684     ZA 00001 R04686     ZA 00002 R07171     ZA 00001 R20067     ZA 00001 R20550     ZA 00001
ALL NHA: ZA 0054  ZB 0008  ZC 0001  ZD 0002  NHA TOTAL 000065
EQPT ZA 000056 ZB 000008 ZC 000001 ZD 000002 EQPT/POP 0000067 PART/POP 00000134

D9/57039660   D29/EP D11/ 000002 D13/4L C7/0001 C7A/000 C7B/
D31/AA D44/X E1/AN/SPS-40C, RADAR SET
NHA: N61797     ZC 00002 RH2525     ZB 00001 RX6296     ZB 00003 R04663     ZD 00001 R04664     ZD 00001
NHA: R04670     ZA 00001 R04678     ZA 00001 R04682     ZA 00001 R04683     ZA 00001 R04684     ZA 00001
ALL NHA: ZA 0046  ZB 0007  ZC 0001  ZD 0009  NHA TOTAL 000063
EQPT ZA 000045 ZB 000009 ZC 000002 ZD 000009 EQPT/POP 0000065 PART/POP 00000130

D9/57039665   D29/EP D11/ 000002 D13/4L C7/0001 C7A/000 C7B/
D31/AA D44/X E1/AN/SPS-40D, RADAR SET
NHA: N0581A     ZC 00001 RX5515     ZD 00001 RX5985     ZD 00001 R03318     ZA 00001 R04661     ZD 00001
NHA: R04666     ZD 00001 R04668     ZA 00001 R04669     ZA 00001 R04672     ZA 00001 R04673     ZA 00001
ALL NHA: ZA 0050  ZB 0009  ZC 0001  ZD 0011  NHA TOTAL 000071
EQPT ZA 000052 ZB 000016 ZC 000001 ZD 000012 EQPT/POP 0000081 PART/POP 00000162

NHA TOTAL    ZA 00150    ZB 00024    ZC 00003    ZD 00022    TOTAL 000199

EQPT TOTAL   ZA 0000153  ZB 0000033  ZC 0000004  ZD 0000023  EQPT/POP 00000213

PARTS TOT    ZA 00000306 ZB 00000066 ZC 00000008 ZD 00000046 PART/POP 000000426
```

Figure 7.   Sample A10 Application Program Output

as an AN/SPS-40B, Radar Set (see the fifth line in Figure 7). To summarize, NIIN 00-889-8110 is installed in the AN/SPS-40B radar set and the radar set has APL number 57039655.

The tenth through fifteenth lines in Figure 7 present information for another equipment. The equipment is identified by APL 57039660. So, Figure 7 shows that NIIN 00-889-8110 is listed as a part of three equipments having APLs 57039655, 57039660, and 57039665.

After the equipment information, the installed population of the NIIN is summarized. In the case of NIIN 00-889-8110, the total installed population is 426 units (see the last line of Figure 7).

The installed populations for the 12 sample DLRs are presented in Table 20.

Table 20. INSTALLED POPULATION FOR THE SAMPLE DLRS

COG, MCC, and NSN	Installed Population
7H H 5840-00-004-2754	213
7H H 1290-00-177-9946	95
7H H 1285-00-182-3756	288
7H H 1285-00-187-6676	58
7H H 5895-00-494-0145	301
7H H 6110-00-889-8110	426
7H H 1440-01-029-1741	578
7H H 1440-01-029-2581	5074
7H H 2040-01-032-9059	95
7H H 2040-01-037-3691	139
7H E 6605-01-112-6484	126
7G H 5820-01-113-7212	1

2. Average Failure Rate (α)

The failure rate is defined as the number of failures that occur in a specified time interval and is expressed as the number of failures divided by the total equipment operating hours or number of failures per hour of calendar time [Ref. 33: p. 25]. The UICP data bases don't contain failure rate data. The Naval Sea Systems Command Logistics Engineering Activity (NAVSEALOGENGACT) in Mechanicsburg, PA also does not maintain failure rate data. However, NAVSEALOGENGACT sends 3M system data to the Naval Warfare Assessment Center (NWAC), Corona, CA for failure analysis [Ref. 34].

NWAC screens the 3M data obtained from NAVSEALOGENGACT to remove all stock replenishment and preventive maintenance demand data. [Ref. 34] The computation of equipment and piece part failure rates are based strictly on corrective maintenance actions.

From the data for 100 weapons systems and weapons related systems in its Material Readiness Data Base (MRDB), NWAC was able to provide the mean time between corrective maintenance actions (MTBCA)[6] for four of the 12 sample DLRs.

6 NWAC refers to the MTBCA as the part level mean time between failures (MTBF).

[Ref. 34] The NSNs for the DLRs, along with the corresponding MTBCA, MTBCA variance, and failure rate (in failures per hour) are listed in Table 21.[7]

Table 21. MTBCA, MTBCA VARIANCE, AND FAILURE RATE FOR FOUR OF THE SAMPLE DLRS

COG, MCC, and NSN	MTBCA (Hrs)	MTBCA Variance	Failure Rate (Failures Hr)
7H H 5840-00-004-2754	24433.21	9786586.08	0.000040927
7H H 1285-00-187-6676	137876.0	3801958275.0	0.000007252
7H H 6110-00-889-8110	70972.67	239862829.2	0.000014089
7H H 1440-01-029-2581	23262.83	45096617.89	0.000042987

MTBCA was estimated by NWAC using the following formula:

$$\text{MTBCA} = \frac{\text{Operating time}}{\text{Number of Failures}} .$$

Then it is easy to compute the failure rate using the following formula: [Ref. 33: p. 24]

$$\text{Failure rate} = \frac{1}{\text{MTBCA}}$$

The operating times and number of failures used to calculate the MTBCAs listed in Table 21 are presented in Table 22.

Table 22. OPERATING TIME AND NUMBER OF FAILURES USED TO CALCULATE MTBCA

COG, MCC, and NSN	Block Operating Time	Number of Part Failures
7H H 5840-00-004-2754	1490426	61
7H H 1285-00-187-6676	689380	5
7H H 6110-00-889-8110	1490426	21
7H H 1440-01-029-2581	279154	12

NWAC wasn't able to provide the operating time of each DLR listed in Table 21 within the time frame allowed for this thesis; therefore, the operating time of the

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7 Table 21 values were drawn from sample data collected by NWAC from 1 January 1985 through 30 June 1989.

block in which the DLR is installed and the actual observed failures of the DLR were used to estimate MTBCA. Block is a term used by NWAC to describe the DLR's next higher assembly that is represented in a reliability block diagram.[8] Note that there may be one, two, or several higher assemblies before the block level is reached. For future studies, NWAC may be able to provide part level operating times, which would improve the accuracy of the MTBCA estimates.

The MTBCA variance was calculated by NWAC using the following formula: [Ref. 34]

$$S^2 = \frac{(MTBCA)^2}{n};$$

where:

S^2 = The estimated variance of MTBCA;

n = Total number of times the part failed.

Notice that by using this variance formula, NWAC assumes that failures follow an exponential distribution. Also, since NWAC couldn't provide part level operating time in the time allowed for this study, this is only a rough estimate of variance and may be very imprecise when n is small. Like MTBCA, the accuracy of the variance will improve when NWAC provides part level operating time data.

The failure rates for the other eight sample DLRs had to be estimated using other methods. Two possible sources of estimates are quarterly demand forecasts and Best Replacement Factors (BRFs). If the quarterly demand forecasts were used to estimate the failure rate, one assumes that all demands for an item are due to failure. There are, however, demands due to new installations of equipment and increases in allowances at all levels of supply. Although SPCC excludes these types of demands as nonrecurring, it's reasonable to assume that not all nonrecurring demands are filtered out. After all, a variety of users, each having a different level of training and interest, are responsible for properly coding their requisitions as nonrecurring. There are also demands where a DLR requires adjustment or alignment only, but the ordering activity doesn't have the maintenance capability to do the adjustment. Demands for DLRs during equipment overhaul and for DLRs that were erroneously replaced also introduce inaccuracies when using demand as an estimate of failure rate.

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8 For a discussion of reliability block diagrams, see Reference 33.

The second possible estimator for failure rates, BRF, is partly based on demand; therefore, BRF suffers from the same inaccuracies as the quarterly demand forecast. [Ref. 22: pp. 1-5] BRF is the estimated replacement rate for an item and represents the number of times in a year an item is expected to be replaced in each of its applications. Calculated as the number of replacements or demands divided by the item's population, BRF is based on demands from a sample population for a one year period. BRF is used to project replacements from a given population and estimate requirements when demand data isn't available. It is used extensively in retail consumer (i.e., COSAL) and retail intermediate (i.e., load lists) allowance documents as an estimate of demand or usage.

Notice that BRF projects replacements from a given population. BRF is the ratio of demand to the population of an item in service during a given time period (i.e., BRF = demand / population year). [Ref. 22: pp. 1-5] The demand data is pulled annually from 3M and CASREP files for active ships only. No demand from overhaul, new construction, reserve, or foreign ships is included. Shore station demand is also not included in the BRF computation.

The number of active ships for the demand sample is narrowed even further using the following criteria: [Ref. 22: p. 3]

- The ship must have submitted 750 usage documents during the past year. A usage document is a copy of a requisition for material.
- The ship must have submitted ten usage documents per month for at least ten months of the past year.
- The ship must have submitted 80 percent of the average number of usage documents for all ships of its type or class.
- A manual review is conducted by NAVSEALOGENGACT to include or exclude individual ships based on any special considerations.

Once the sample ships are selected, a replacement factor for the past year is computed. [Ref. 22: pp. 1-5] For each NSN, the total demands from the ships in the sample are divided by the total NSN population from the ships in the sample to get the replacement factor. Note that the demand and population data are for the sample ships only. That is, they are a subset of total demand and total population. The replacement factor is used as an input to a simple exponential smoothing equation to forecast the BRF.

BRF is similar to failure rate in that BRF and failure rate are both ratios measured over a given period of time. [Ref. 22: p. 2] Failure rate, however, is the ratio of

failures to operating hours during a given time period (i.e., α = number of failures / total operating hours), while BRF is the ratio of replacements to population during a given time period. BRF and α are both used to predict the number of events expected in some future period of time for some known population, and both are subject to bias due to faulty classification (i.e., an item was replaced, but didn't fail). However, a BRF can be zero if:

- The item wasn't demanded because it never failed.
- The item wasn't demanded because when it failed, it wasn't replaced. Instead, the next higher assembly was replaced.
- The item wasn't demanded because when it failed, the individual parts within that item were replaced (i.e., the item was repaired locally).

So, an item can have a BRF equal to zero even if it experienced failures [Ref. 22: p. 2]. Thus, BRF will be less than or equal to α [Ref. 22: p. 4]. Reliability theory provides another way to look at this problem. [Ref. 33: p. 208] Here:

$$\alpha_{system} = \alpha_A + \alpha_B + \alpha_C + \dots + \alpha_n$$

where α_A, α_B, ..., α_n are failure rates for the subassemblies that make up the system. If a system consists of subassemblies A, B, C and if A fails, causing the system to fail, a failure occurrence should be assigned to both subassembly A and the system. With the BRF, a replacement occurrence would only be assigned to the system if the system was ordered from supply. Likewise, a replacement occurrence would be assigned to subassembly A if it were ordered. Thus, BRF is a function of the type of failure and the maintenance philosophy.

In the case of a DLR, the organizational level of maintenance will usually demand the DLR itself or the next higher assembly. If the failed DLR (i.e., a circuit card) is a part of a larger DLR (i.e., a radio receiver) and the organizational level removes and replaces the circuit card, the circuit card BRF reflects the failure, but the radio receiver BRF does not reflect the failure. If, however, the radio receiver was replaced, a demand for the receiver would register at the organizational level and a demand for the circuit card might be recorded at the repair depot if the circuit card is replaced from supply and repaired later.

Recall that NWAC provided failure rate data for four sample DLRs. In order to get an idea of the magnitude of difference between failure rate, BRF, and forecasted quarterly demand, the failure rates obtained from NWAC were converted from

failures/hour to failures/year[9] and the quarterly demand forecasts were converted to replacements per year.[10] The failure rates, BRFs, and demand (converted to replacements/year) for the four DLRs are presented in Table 23.

Table 23. FAILURE RATE VS. BRF AND DEMAND DATA FOR FOUR OF THE SAMPLE DLRS

COG, MCC, and NSN	Failure Rate (Failures/Yr)	BRF (Replacements/Yr)	Demand (Replacements/Yr)
7H H 5840-00-004-2754	0.358521	0.19	0.073742
7H H 1285-00-187-6676	0.063528	0.042	0.002203
7H H 6110-00-889-8110	0.123420	0.041	0.034329
7H H 1440-01-029-2581	0.376566	0.05	0.001654

It can be seen that neither the quarterly demand forecasts or the BRFs are accurate estimates of failure rate, but the use of BRF is recommended for future studies based on the results presented in Table 23.

3. Number Of Repair Channels (c)

The number of repair channels, or stations, at each DOP is not available in SPCC's UICP files. Repair channel information was gathered through telephone conversations with DOP representatives for the 12 sample DLRs. Through discussions with the DOPs, several findings are important to note for future studies.

- The number of repair channels at a particular DOP may change as often as each six months, particularly for electronic DLRs. SPCC's semiannual workload conference provides the DOPs with an estimate of the workload for the next six months. Based on this estimate, a DOP may reallocate skilled workers to other projects when repair work drops off or increase the number of repair channels as workload expands. All of the DOPs for the 12 items sampled had enough skilled workers and equipment to expand the number of repair channels by at least one. For future studies, it's reasonable to assume that the number of repair channels remains constant for the six months between workload conferences.
- Different DOPs have different production stages in the repair process and may have a different number of repair channels in each stage. The repair process is dependent on the DLR being fixed, the DOP structure, and the DOP repair equipment. The three most common stages can be described as testing/fault

9 The failure rate was converted to failures/year by multiplying the failures/hour value by 8760 (i.e., the number of hours in a year).

10 To convert forecasted demand to replacements/year, the quarterly demand forecast (B023D) was multiplied by four to get an annual demand estimate. The annual demand estimate was then divided by total population to get the replacements/year.

isolation, repair, and inspection. For the 12 DLRs sampled, three DOPs were using more than one repair channel and all three DOPs had fewer testing fault isolation and inspection stations than repair stations. Assuming that the actual repair time was the largest part of the service time, the number of repair channels in the repair stage was used to represent the number of repair channels variable for the proposed model.

- Collecting repair channel information can be done more efficiently at the SPCC workload conference held every six months. SPCC would have to tell all DOPs to bring the information to each repair conference. Also, to get the repair channel information into the UICP data base would require adding a data field or redesignating an unused data field for this purpose. While adding a new data field is unrealistic, redesignating a field no longer used is a possibility. Coordinating repair channel reporting and finding an unused data field were tasks that couldn't be done in the time allowed for this thesis, but that must be accomplished before a large sample of DLRs is used in an expanded study.
- Although one of the selection criteria for the sample NSNs was to find a specialized repair activity, the experience gained by the author in this study suggests that no DOP repairs less than about 30 line items for the Navy. The number of line items repaired varies each six months with the workload forecast.
- For all of the 12 sample DLRs, the repair channels were not dedicated to the DLR of interest. This was particularly true in the case of circuit cards where test and repair equipment is designed to repair many different types of circuit cards. This is significant in that queueing time for a particular item is dependent on the service time for the item being serviced and the service time for all of the different types of items already in the queue. For this study, the average service times collected from the DOPs were for the individual item and not the repair channel.

4. Average Repair Rate Per Repair Channel (μ)

As noted in the last section, repair rates per channel can't realistically be used because there may be many different items being fixed by each repair station. Instead, the average repair time for each individual item in the sample was collected from the DOPs.

The question may be: why not use RTAT? To understand why RTAT is not an appropriate estimate of μ requires an understanding of how RTAT is being measured at SPCC.

While SPCC maintains a forecasted RTAT, this value doesn't accurately reflect the service time because RTAT includes other time elements in addition to the service or repair time. SPCC defines RTAT as the time from receipt of a repair funding document and a carcass at the DOP, to the time the DLR is reported into A condition [Ref. 28]. In practice, SPCC knows that a funding document and a carcass are available when a TIR is received transferring a carcass from F to M condition. Thus, the M condition TIR starts the RTAT clock and the A condition TIR stops the RTAT clock. The key,

then, is determining when the M and A condition TIRs are sent, but this depends on the activity. Navy organic DOPs, reporting commercial DOPs, and nonreporting commercial DOPs all have slightly different procedures. These procedures are discussed in the following sections.

a. Navy Organic DOP

Organic DOPs are usually Naval shipyards, NESECs, weapons stations and ordnance stations. As previously discussed, organic DOPs have DSPs that send the TIRs to SPCC and store F condition carcasses. The DSP for a shipyard is usually the local NSC and the DSP for a repair facility not near a supply center is the repair facility's supply department [Ref. 12: p. 3]. After the DSP gets an induction order from the DOP, it pulls the material, ships the carcass, and submits the TIR reporting the item into M condition. The RTAT clock then starts. When the DOP completes repair, the item is shipped back to the DSP for packaging and storage or shipment. The TIR reporting the item in A condition isn't sent until the item is either back on the shelf or shipped. In any event, it's easy to see that RTAT contains shipping time, receiving time, DOP administrative time, queueing time, awaiting parts time, servicing time, packaging time, and DSP administrative time. It should be noted that if awaiting parts time is anticipated to be longer than 30 days, the DOP usually sends the item back to the DSP until parts are available. The DSP then sends a G condition TIR to SPCC (which stops the RTAT clock). At least one study at the Naval Postgraduate School, however, shows that some DOPs don't extensively use the G condition TIR. [Ref. 26: p. 42] Thus, actual RTAT observations may contain a large amount of awaiting parts time.

b. Commercial Reporting DOPs

Commercial reporting DOPs are those using the Commercial Asset Visibility, Phase II (CAV II) system. The statement of work in SPCC's CAV II contract states that, "CAV II allows the commercial DOP to report in the same fashion as a Navy organic DOP." In fact, the commercial DOPs using CAV II report RTAT that has no shipping time and little administrative time when the computer terminal for doing the TIRs is located at the DOP (i.e., the vendor's plant). There are large commercial vendors that have one CAV II terminal supporting DOPs in several geographical areas. These large vendors have an administration time similar to that of an organic DOP, but no shipping time in their RTAT observations. [Ref. 35]

The CAV II statement of work also states:

> Upon receipt of a delivery order to begin repair of an item previously reported as a receipt, the carcass is to be reported as an induction under the Repair Cycle Document Number (RDCN).

So, unlike the organic DOP, the commercial DOP using CAV II already has the carcass and can schedule the repair before the M condition TIR is sent. Upon completion of the repair, the commercial DOP reports the date the repair was actually completed on the A condition TIR. This actual completion date, however, is not used to compute the RTAT. Instead, the TIR transmission date is used to calculate the RTAT. The actual completion date is input to an off line data base at SPCC and used to monitor contractor administrative processing time. [Ref. 35]

Currently, 53 of the 200 commercial DOPs use CAV II. The work done at these 53 DOPs accounts for 80 percent of SPCC's repair dollars [Ref. 28].

c. Commercial Nonreporting DOPs

Commercial nonreporting DOPs are those activities not using the CAV II system. Although there are about 147 of these DOPs, they account for only about 20 percent of the commercial repair dollars. These non-CAV II DOPs submit a monthly repair status report to SPCC. The repair status report provides the induction dates and completion dates for DLRs entering or leaving the repair process during the past month. SPCC manually calculates the RTAT from these reports and enters the RTAT into the UICP files. Although not timely, RTAT calculated from the monthly repair status reports contains less administrative time than either an organic or a CAV II DOP because the RTAT is calculated using induction and repair dates instead of TIR transmittal dates.

After researching the different ways RTAT observations are being measured, it's apparent that RTAT is not a good estimate for the average repair rate. Therefore, data was collected directly from the DOPs for both number of repair channels (c) and average service rate (μ).

5. Summary

All of the variable data needed for the proposed model were available from the UICP files except for the:

- Number of repair channels (c).
- Average failure rate (α).
- Average repair rate per channel (μ).

The data for c and μ were collected directly from the DOPs. The data for α can be obtained from NWAC, if available, or can be estimated from quarterly demand forecast (D) or BRF from the UICP files. The demand (B023D) data available in the UICP files was presented in Tables 15 and 16. The data for c, μ , BRF, and α (when available) are presented in Table 24. RTAT is also presented for information.

Table 24. ADDITIONAL DATA NEEDED FOR THE PROPOSED MODEL

COG, MCC, and NSN	# Channels (c)	Repair Rate (μ) Hours/unit	BRF	Failure Rate (α) Failures/Yr	RTAT Qtrs
7H H 5840-00-004-2754	1	9	0.19	0.358529	1.87
7H H 1290-00-177-9946	2	12	0.071	unavailable	4.15
7H H 1285-00-182-3756	2	10.5	0.045	unavailable	3.66
7H H 1285-00-187-6676	1	4.5	0.042	0.063535	5.86
7H H 5895-00-494-0145	1	56	0.0004	unavailable	0.3
7H H 6110-00-889-8110	1	8	0.041	0.061714	0.56
7H H 1440-01-029-1741	1	73.5	0.078	unavailable	0.69
7H H 1440-01-029-2581	1	2.8	0.05	0.094142	0.42
7H H 2040-01-032-9059	1	unknown	0.0034	unavailable	2.7
7H H 2040-01-037-3691	1	1288	0.14	unavailable	4.0
7H E 6605-01-112-6484	2	488	1.408	unavailable	1.24
7G H 5820-01-113-7212	1	4	0.09	unavailable	1.04

Note that for NSN 2040-01-032-9059, the repair rate (μ) was not recorded. The DOP, Sperry Marine, was unable to extract the repair hours per unit for this NSN. The item is a periscope panel that has a light fixture and two knobs mounted on a metal plate. [Ref. 36] The item is usually repaired or refurbished as part of the repair work done on entire periscope systems. The hours spent working on the periscope panel are not specifically tracked, but are absorbed into the total hours spent working on the periscope.

V. ANALYSIS OF THE PROPOSED MODEL'S ASSUMPTIONS

The assumptions for the proposed low attrition DLR inventory control process were presented in Chapter III. Four of the model's key assumptions are addressed in this chapter. The assumptions discussed are:

- That a M/M/1/K/K or M/M/c/K/K queueing model is appropriate for the repair process.
- That the item manager (IM) at the ICP has total asset visibility. That is, the IM has access to information about the number of units installed, wholesale RFI units on hand, retail intermediate RFI units on hand, retail consumer RFI units on hand, and NRFI units on hand.
- That the IM has visibility of the number of repair channels at the DOPs, the failure rate for each DLR, and the service rate for each repair station.
- That NRFI DLRs enter the repair system as soon as they are removed from the primary system and shipped to the DSP or DOP. Alternatively, carcasses are inducted for repair in batches equal to a specified repair quantity.

A. THE M/M/1/K/K OR M/M/C/K/K ASSUMPTION

1. Arrivals

The validity of two assumptions concerning arrivals must be examined:

- The assumption that interarrival times follow an exponential distribution.
- The assumption that the failure rate and the arrival rate are equivalent. That is, when a DLR fails, the model assumes that the DLR enters the repair system immediately.[11]

For the moment, assume that the failure rate and the arrival rate are equivalent. In this case, the mean time between failures (MTBF), or mean time between corrective maintenance actions (MTBCA), represents the interarrival time. Since failure rate estimates were only available for four of the sample DLRs, examination of the exponential interarrival time assumption must be restricted to these four items.

Under both the M/M/1/K/K and M/M/c/K/K assumptions, the interarrival time is assumed to follow an exponential process. If interarrival times follow an exponential distribution, then the square of the mean should be approximately equal to the variance [Ref. 11: p. 156]. In this case, the mean is the mean time between corrective maintenance actions (MTBCA). If the square of the mean and the variance are

11 This assumes batch inductions are not used.

expressed as a ratio, referred to as the squared coefficient of variation (C^2), then this ratio, $C^2 = \frac{S^2}{(MTBCA)^2}$, should be approximately equal to one. Recall that the MTBCA and the MTBCA variance were obtained from the Naval Warfare Assessment Center (NWAC) and were presented in Chapter IV. The MTBCA, MTBCA variance, and C^2 for four of the sample DLRs is presented in Table 25.

Table 25. MTBCA, MTBCA VARIANCE, AND C^2 FOR FOUR OF THE SAMPLE DLRS

COG, Material Control Code (MCC), and NSN	MTBCA	MTBCA Variance	C^2
7H H 5840-00-004-2754	24433.21	9786586.08	0.016393
7H H 1285-00-187-6676	137876.0	3801958275.0	0.20
7H H 6110-00-889-8110	70972.67	239862829.20	0.047619
7H H 1440-01-029-2581	23262.83	45096617.89	0.083333

Since none of the C^2 values in Table 25 are close to one, the arrival pattern doesn't appear to be exponential [Ref. 20 : p. 156]. However, as noted in Chapter IV, the MTBCA and MTBCA variance are only rough estimates. Additional analysis must be done after NWAC provides more precise part level failure rate data.

The implied assumption that the failure rate is equivalent to the arrival rate is the second issue that must be examined. Clearly, from the discussion of the induction process in Chapter IV, not all DLRs enter the repair process immediately after failure. A DLR's entry into the repair process is often determined by the need for ready for issue (RFI) assets and repair budget dollars available. If a failed DLR is required for immediate use or to replenish stock, and repair funding is available, the item will be inducted for repair immediately. If, however, the DLR isn't required immediately, or repair funding isn't available, the carcass is stored at the designated support point (DSP) until it's required and funding is available.

Since it's unlikely that the system used to induct carcasses for repair will change soon, the interarrival times should be measured directly. The historic time between arrivals can be measured for each DLR by using the Transaction History File (THF) discussed in Chapter IV. SPCC maintains two years of THF data, but a program to calculate the interarrival time from the THF data must be developed in a future study.

2. Service Rate

The M/M/1/K/K and M/M/c/K/K queueing systems also assume an exponential service rate. As noted in Chapter IV, average service rates were available at most DOPs, but individual service times for each item serviced was not provided; thus, variances could not be calculated. From discussions with DOP representatives about the repair processes used for the sample DLRs, the author believes that the service rates for the sample DLRs are closer to being constant than exponential.

Better data needs to be collected in a future study to examine the exponential service rate assumption. Also, the impact of servicing several different DLRs at the same repair station must be researched in a future study.

3. Number of Servers or Repair Channels

The number of servers used at the DOPs varies, but, as noted in Chapter IV, all of the DOPs contacted for this study had the capability to increase the number of repair channels by at least one.

As discussed in the last chapter, future work on the proposed model should include coordinating the reporting and recording of the number of repair channels being used at each DOP. Assuming that information about the number of repair channels will be automated, the program developed to set inventory levels should be designed to calculate the target, minimum population (S_t) based on the single server or multiple server case as appropriate.

4. Queueing System Capacity and Source Population Size

The assumption that the queueing system capacity and source population size (the K/K in the M/M/c/K/K notation) are finite and equal is valid for low attrition DLRs. It should be noted that the source population for a DLR with a low attrition rate may be less stable than a population of industrial machines for which the M/M/1/K/K and M/M/c/K/K queueing systems were designed. Installation and retirement of equipment affect installed population, while allowance changes, attrition, and emergency procurements effect the spares population.

B. THE ITEM MANAGER HAS TOTAL ASSET VISIBILITY

As discussed in Chapter IV, the IM can have visibility of installed units by using an A10 application program retrieval. The number of units installed is an important input variable to the proposed levels computation and it is also a part of the total assets owned.

The IM also has visibility of NRFI units being stored at a DSP or being repaired at a DOP, because the status of all failed DLRs at DSPs and DOPs is reported under the TIR system. However, the IM doesn't have visibility of failed units in route to the DSP or DOP from the end user. For the purposes of this model, having visibility of NRFI units at the DSPs and DOPs is sufficient to accurately represent reality.

The visibility of RFI spares at all levels of supply -- wholesale, retail intermediate, and retail consumer -- isn't possible with current information systems. The wholesale RFI on hand balances and the RFI on hand balances for the retail intermediate activities that submit daily TIRs are visible to the IM. However, the RFI on hand balances from retail intermediate activities such as tenders and AFSs are not visible to IMs. In addition, no retail consumer level on hand balances are visible to the IMs.

While the RFI on hand balances are not necessary to compute levels with the proposed model, these RFI balances are important when comparing what the Navy already owns to the quantity calculated by the proposed levels model. That is, after levels are computed, the next step involves comparing inventory position (IP) with the reorder level and placing an order of quantity Q if the IP is at or below the reorder level. The total quantity owned, which includes RFI spares at all levels, must be visible to calculate the IP.

This lack of visibility of RFI spares is a major issue that must be resolved through future study. There are two possible solutions to the dilemma:

- Wait until the Navy's Secondary Item Weapon System Management (SIWSM) information system can provide asset visibility [Ref. 2: p. D-1].
- Use allowance information to estimate the RFI units owned.

Developing IM asset visibility down to the lowest echelon of supply is one of the SIWSM system's objectives. [Ref. 2: p. D-1] This means that the current UICP constraint of 45 transaction reporting activities will be eliminated and that all retail intermediate and shore based retail consumer levels will be required to submit asset status reports whenever the on hand balance or material condition of a DLR changes.

Although the SIWSM system will eventually provide excellent asset visibility, the project isn't scheduled for completion until 2005 [Ref. 2: p. 7]. Also, afloat retail consumer activities aren't included in the SIWSM system planning document. Therefore, allowance information appears to be the best estimate of on hand assets for the present.

Allowance information, however, has some drawbacks when used as an estimate of RFI assets on hand. The DLR allowance for a ship only indicates how much RFI

material should be on hand; thus, the allowance will usually be greater than or equal to the on hand quantity. One way to compensate for this overestimation would be to subtract the on order quantities for nonreporting retail intermediate activities (i.e., tenders) and retail consumer activities from the allowance quantities and use this adjusted allowance as an estimate of the on hand RFI balances. Excluding the on order quantities might be an effective compensation tool since retail activities usually order DLRs soon after issuing them from stock. That is, retail activities always try to keep their full allowance quantities of DLRs on hand or on order. Using this procedure to estimate the RFI on hand balances would, however, only be accurate for a very short time since the quantity on order for each DLR can change often.

Unfortunately, a single number representing the Navy wide allowance for each DLR isn't available in any UICP data base. Instead, allowance information is fragmented into numerous allowances for Coordinated Shipboard Allowance Lists (COSAL), Fleet Issue Load Lists (FILL), Tender And Repair Ship Load Lists (TARSLL), prepositioned war reserve stocks, nuclear reactor plant (Q) COSALs, Fleet Ballistic Missile (FBM) submarine protection levels, Strategic Weapons System (SWS) COSALs, test equipment, and Operational Support Inventory (OSI) items. OSI items include allowances contained in Consolidated Shore Based Allowance Lists (COSBAL), geographic support allowance documents, Ships Intermediate Maintenance Activity (SIMA) allowance lists, special project allowance lists, and Selected Restricted Availability Stock Lists (SRASL) [Ref. 37]. In addition, other allowance lists and/or small unauthorized inventories may exist.

While finding and investigating all of the allowance sources was beyond the time allowed for this thesis, Table 26 lists the allowance documents that were investigated, the SPCC source file that contains the allowance information, and the SPCC points of contact (POCs). Table 27 provides the actual total allowance quantities from the documents listed in Table 26 for each of the 12 sample DLRs.

An entire thesis could be devoted to developing, retrieving, and combining allowance information for use with the proposed model. Finding and retrieving the information necessary to make the total asset visibility assumption valid for the proposed model will, thus, be a major task.

Table 26. ALLOWANCE INFORMATION SOURCES AND POCS

Allowance Document	Source File or Data Base	SPCC POC
All ships' Hull, Mechanical, Electrical, Ordnance & Electronic (HMEO&E) COSALs	Ship's History File	Vera Miller Code 04221 A/V 430-4349
FILL/TARSLL	Focus data base	Kathy Bower Code 03312 A/V 430-5181
Retail OSI Allowances	Focus data base	Glenn Huffer Code 03352 A/V 430-3681
FBM Protection Levels	Focus data base	Judy Mannix Code 8432 A/V 430-7111
Prepositioned War Reserve	Manual Listing	Larry Kohler Code 0411 A/V 430-2407

Table 27. ALLOWANCE INFORMATION FOR THE SAMPLE DLRS

	Allowance From:					
NIIN	HMEO&E COSAL	FILL/ TARSLL	Retail OSI	FBM Protection Levels	Prepositioned War Reserve	Total
00-004-2754	70	17	8	0	2	97
00-177-9946	39	0	5	0	7	51
00-182-3756	37	12	6	0	0	55
00-187-6676	26	0	0	0	3	29
00-494-0145	0	0	0	0	0	0
00-889-8110	34	12	11	0	2	59
01-029-1741	374	0	4	0	0	378
01-029-2581	957	0	6	0	3	966
01-032-9059	1	0	0	0	0	1
01-037-3691	0	8	5	0	0	13
01-112-6484	53	0	0	0	36	89
01-113-7212	4	0	0	0	0	4

C. ITEM MANAGER VISIBILITY OF REPAIR CHANNELS, FAILURE RATE, AND REPAIR RATE

As discussed in Chapter IV, the IM doesn't have visibility of the number of repair channels (c) used at the DOPs, failure rate (α) for each DLR, or repair rate (μ) for each repair station.

Although manually collected for this thesis, the automated collection of the data for c and μ will require extensive coordination with SPCC's Repairables Support Department (code 03). As discussed earlier in this chapter and in Chapter IV, the data for c could be collected at SPCC's semiannual repair conferences. Reporting and recording the individual repair or service rates requires the development of new transaction reporting procedures for Navy DOPs, CAV II commercial DOPs, and non-CAV II commercial DOPs.

Developing the new transaction reporting procedures was beyond the scope of this thesis; however, the monthly repair status reports submitted by all DOPs could be used as a tool to collect actual repair times for DLRs. In addition, the possibility of including actual repair time on transaction reports must be investigated as a future thesis topic.

As already discussed earlier in this chapter, the failure rate doesn't accurately represent the arrival rate, but interarrival rates can be measured by using THF data and a computer program designed to calculate the time between arrivals from the THF records.

D. NRFI DLRS ENTERING THE REPAIR PROCESS

As discussed in Chapter III, the proposed model assumes that carcasses are inducted for repair as soon as they are removed from their parent equipment and shipped to the repair facility. The model can also be adapted for batch inductions. That is, when the number of failed units for a given DLR reaches a level equal to the repair quantity, all of the on hand carcasses are inducted for repair.

The assumption that failed DLRs enter the repair process as soon as they are removed from the primary system and shipped to the DOP is not valid in many cases. This assumption supports the assumption that the failure rate and the arrival rate are equivalent, but, as already discussed, neither of these assumptions accurately represents reality. By measuring actual interarrival times from the THF, an assumption about when a failed DLR enters the repair process is not necessary to support the failure rate equals arrival rate assumption.

An assumption about when not ready for issue (NRFI) DLRs enter the repair process is necessary, however, to plan inductions to the repair process. In reality, on hand RFI assets, customer demands, and the repair budget determine what items are repaired and when those items will be repaired. As seen in Chapter IV, half of the initial sample randomly selected had NRFI units on hand, but no repair inductions for at least two years. So, compared to current practices, neither the immediate induction assumption or the batch induction assumption is accurate for all DLRs. DLRs scheduled for repair at the semiannual repair conferences are being inducted for repair as soon as the carcasses are received. For these items, the immediate repair process entry assumption does hold, but the mix of items scheduled for repair may change every six months. As discussed in Chapter IV, for those items where the immediate repair assumption does not hold, the proposed inventory control process will only work if current practices are changed.

The question for further study is whether or not established procedures should be changed to fit the model or a different model used to accurately represent current practice. Does the Navy save money by not repairing all carcasses when received? The author's personal experiences with FBM submarine priority one requisitions for DLRs suggests that the Navy may not be saving money. The Atlantic fleet FBM submarine force spends a tremendous amount of time and money purchasing new DLRs, so that ships can meet deployment schedules. Often, there are F condition assets on the shelves at the DSPs, but not enough time to make repairs and meet deployment schedules. In addition to the money for new DLRs, additional purchasing personnel and expediting costs are incurred. Again, more study must be done on this subject before any inventory control process decision can be reached.

VI. CONCLUSIONS AND RECOMMENDATIONS

The major thrust of this thesis has been to see if data for the proposed inventory process can be collected and to identify issues that need further research. As pointed out at the end of the last chapter, major changes in the repair induction procedures would be required for the proposed inventory control process to function properly.

Certainly, for a small sample, this thesis has shown that the data can be collected for the proposed levels model; however, the ability to use the levels output to control the inventory process is an issue that this thesis did not evaluate. Asset visibility, as discussed in Chapter V, is the major stumbling block to effectively controlling the proposed inventory control process.

For a large sample of DLRs, the automated or semi-automated data collection procedures and processes required to support the proposed model do not exist, but can be developed without a lot of capital investment. Developing these automated or semi-automated data collection procedures and processes will, however, require a large investment of time. This large investment could be made by several thesis students working in several areas simultaneously. These areas for further study include:

- Developing a program to calculate the interarrival times from Transaction History File (THF) data and determining the distribution of the interarrival times.
- Programming the proposed levels setting model to accommodate both the single server and multiple server cases.
- Coordinating, through SPCC, the reporting and recording of the number of repair channels used at each DOP.
- Coordinating, through SPCC, the reporting and recording of service time data from the DOPs.
- Resolving the lack of item manager asset visibility issue by collecting and using allowance data as an estimate of the ready for issue (RFI) spares on hand at non-transaction item reporting (non-TIR) activities.
- Performing a cost analysis that compares the cost of immediate induction to the repair process and current practices.

Without further study, it's impossible to make conclusions about the feasibility of the proposed model. As shown, significant study is still required.

APPENDIX A. SPCC UICP DLR MODEL PROGRAM

```
//DEXA9864 JOB (9864,9999),'M.DEXTER',CLASS=A
//  EXEC FORTVCLG,IMSL=IMSL10
//FORT.SYSIN  DD  *
************************************************************************
* TITLE   : UICP REPAIRABLES MODEL                                     *
* DATE    : 23 AUGUST 1989                                             *
* AUTHOR  : MARK D. DEXTER, LT, SC, USN                                *
*           I GRATEFULLY ACKNOWLEDGE THE HELP I RECEIVED FROM PROFESSOR*
*           A. W. MCMASTERS.  MANY OF THE IDEAS AND CODING FOR THIS    *
*           PROGRAM WERE EXTRACTED FROM PROFESSOR MCMASTERS' REPMOD1   *
*           PROGRAM.                                                   *
* SYSTEM  : IBM 3033                                                   *
* COMPILER: FORTRAN LEVEL 77 VERSION 4.1                               *
*                                                                      *
************************************************************************
*                             DESCRIPTION                              *
************************************************************************
*                                                                      *
* THIS PROGRAM USES THE SPCC LEVELS FORMULAS TO COMPUTE THE REORDER    *
* LEVEL, REORDER QUANTITY, REPAIR LEVEL, AND REPAIR QUANTITY FOR DEPOT *
* LEVEL REPAIRABLE (DLR) MATERIAL.  THE MAJOR REFERENCE USED WAS THE   *
* FLEET MATERIAL SUPPORT OFFICE'S (FMSO) UNIFORM INVENTORY CONTROL     *
* PROGRAM (UICP) FD-D01 MANUAL.  THE FD-D01 MANUAL IS DATED 31 MARCH   *
* 1984 WITH CHANGE 1 DATED 22 FEB 1985.                                *
*                                                                      *
************************************************************************
*                         VARIABLE DEFINITIONS                         *
************************************************************************
*                                                                      *
*     AAC    = ACQUISITION ADVICE CODE.                   (DEN E089)   *
*     AC     = ADMINISTRATIVE COST TO REPAIR ONE ITEM.    (DEN V016)   *
*     AS1    = MANUFACTURER'S SETUP COST.                 (DEN B058)   *
*     AUTHLV = LEVEL OF AUTHORITY.                        (DEN D120)   *
*     A1     = PROCUREMENT ORDERING ADMINISTRATIVE COST.  (DEN V043)   *
*     A2     = REPAIR SETUP COST.                         (DEN B058A)  *
*     COG1   = TWO DIGIT COGNIZANCE SYMBOL                (DEN C003)   *
*     COG2   = THE THIRD AND FOURTH DIGITS OF THE 4 DIGIT COG.  THE    *
*              FIRST DIGIT OF COG2 IS THE ITEM'S ITEM MILITARY         *
*              ESSENTIALITY CODE (IMEC).  THE SECOND DIGIT TELLS US    *
*              IF THE ITEM IS WEAPONS SYSTEM RELATED AND THE RANGE     *
*              OF THE REQUISITION FREQUENCY.              (DEN C003W)  *
*     C1     = REPLACEMENT COST                           (DEN B055)   *
*     C2     = REPAIR COST                                (DEN B055A)  *
*     D      = GROSS SYSTEM DEMAND FORECAST - END OF LEAD TIME.        *
*                                                         (DEN B023D)  *
*     DBAR   = QUARTERLY DEMAND FORECAST.                 (DEN B074)   *
*     DLT    = GROSS SYSTEM DEMAND DURING LEAD TIME.      (DEN B023C)  *
*     DRTAT  = RANDOM DEMAND DURING REPAIR PROBLEM TURN AROUND TIME.   *
*                                                         (DEN B023H)  *
*     DSCNTQ = DISCOUNT QUANTITY.  A PARAMETER USED BY SPCC TO         *
*              CONSTRAIN THE PROCUREMENT ORDER QUANTITY.  (DEN B061)   *
```

```
*      E      = MILITARY ESSENTIALITY.                        (DEN C008C)  *
*      G      = GROSS SYSTEM RFI REGENERATIONS FORECAST - END OF LEAD      *
*               TIME.                                         (DEN B023F)  *
*      GLT    = SYSTEM RFI REGENERATIONS DURING LEAD TIME.    (DEN B023E)  *
*      GRTAT  = RFI REGENERATIONS DURING PROCUREMENT PROBLEM AVERAGE       *
*               TURN AROUND TIME.                             (DEN B023G)  *
*      H      = ANNUAL HOLDING COST FOR REPAIRABLES.                       *
*                          .              (DEN V108 + .01 + DEN B057)      *
*      I      = VARIABLE USED AS A COUNTER FOR DO LOOPS.      (NO DEN  )   *
*      LAMBDA = SHORTAGE COST ASSUMED WHEN A STOCKOUT OCCURS(DEN V104)     *
*      LOT    = LIFE OF TYPE.  A CODE THAT TELLS US WHEN THE ITEM'S        *
*               SPARES FOR IT'S LIFE CYCLE WERE BOUGHT IN A ONE TIME       *
*               BUY.                                          (DEN B070 )  *
*      MQTRSL = MAXIMUM NUMBER OF QUARTERS OF SAFETY STOCK.(NO DEN    )    *
*      N      = THE NUMBER OF ITEMS OR NIINS THAT REQUIRE LEVELS           *
*               COMPUTATIONS.                                 (NO DEN   )  *
*      NIIN   = NATIONAL ITEM IDENTIFICATION NUMBER CODE.     (DEN D046D)  *
*      NIMSC  = NONCONSUMABLE ITEM MATERIAL SUPPORT CODE.     (DEN D125N)  *
*      NRPR   = NUMBER OF POLICY RECEIVERS.  THAT IS, THE NUMBER OF        *
*               STOCK POINTS THAT WILL STOCK THIS ITEM.       (DEN A003 )  *
*      NSO    = NUMERIC STOCKING OBJECTIVE.  SOMETIMES CALLED SYSTEM       *
*               REORDER LEVEL LOW LIMIT QUANTITY.             (DEN B020 )  *
*      PBP    = PROBABILITY BREAK POINT.  COMPARED TO THE PROCUREMENT      *
*               PROBLEM VARIABLE (IE. AVERAGE LEAD TIME DEMAND) TO         *
*               DETERMINE WHICH DISTRIBUTION TO USE WHEN CALCULATING       *
*               THE REORDER POINT.                            (DEN V028 )  *
*      PVAR   = PROCUREMENT PROBLEM VARIANCE.                 (DEN B019A)  *
*      Q      = CONSTRAINED PROCUREMENT ORDER QUANTITY.       (DEN B021)   *
*      QW     = UNCONSTRAINED PROCUREMENT ORDER QUANTITY.  CALCULATED      *
*               USING THE WILSON EOQ FORMULA ADJUSTED FOR                  *
*               REGENERATIONS.                                (NO DEN   )  *
*      QR     = CONSTRAINED REPAIR QUANTITY.                  (DEN B021A)  *
*      QREOQ  = UNCONSTRAINED REPAIR QUANTITY.  CALCULATED USING THE       *
*               WILSON EOQ MODEL.                             (NO DEN   )  *
*      QR1    = BASIC REPAIR QUANTITY.  CONSTRAINTS APPLIED TO QREOQ       *
*               YIELD THIS VARIABLE.                          (NO DEN   )  *
*      Q1     = BASIC PROCUREMENT ORDER QUANTITY.  CONSTRAINTS APPLIED     *
*               TO QW YIELD THIS VARIABLE.                    (NO DEN   )  *
*      RF     = REQUISITION FREQUENCY.                        (DEN A023B)  *
*      RISK   = CONSTRAINED PROCUREMENT STOCKOUT RISK OR THE PROBABIL-     *
*               ITY OF A STOCKOUT.                            (NO DEN   )  *
*      RLCONS = REORDER LEVEL CONSTRAINT RATE.  USED TO CONSTRIAN THE      *
*               PROCUREMENT REORDER POINT.                    (DEN V295)   *
*      RMAX   = MAXIMUM ALLOWABLE RISK.  USED TO CONSTRAIN RISK.           *
*                                                             (DEN V102 )  *
*      RMIN   = MINIMUM ALLOWABLE RISK.  USED TO CONSTRAIN RISK.           *
*                                                             (DEN V022 )  *
*      ROP    = CONSTRIANED PROCUREMENT REORDER POINT OR LEVEL.            *
*                                                             (DEN B019 )  *
*      ROPBAS = UNCONSTRIANED PROCUREMENT REORDER POINT OR LEVEL.          *
*                                                             (NO DEN   )  *
*      RRCT   = REPAIR REVIEW CYCLE TIME.                     (DEN V039 )  *
*      R2     = CONSTRAINED REPAIR LEVEL.                     (DEN B019B)  *
*      R2BAS  = UNCONSTRIANED REPAIR LEVEL.                   (NO DEN   )  *
*      SL     = SHELF LIFE.  A REAL VARIABLE THAT REPRESENTS THE SHELF     *
*               LIFE IN QUARTERS.                             (NO DEN   )  *
```

```
*     SLC     = SHELF LIFE CODE.  A CHARACTER VARIABLE THAT MUST BE      *
*               TO QUARTERS FOR USE IN OTHER PARTS OF THE PROGRAM.        *
*                                                       (DEN C028 )  *
*     Z       = PROCUREMENT PROBLEM VARIABLE.  THINK OF AS LEAD TIME      *
*               ATTRITION DEMAND.                       (NO DEN    )  *
*                                                                     *
***********************************************************************
*                         VARIABLE DECLARATIONS                       *
***********************************************************************
*                                                                     *
      INTEGER DSCNTQ(12),I,LOT(12),N,NRPR(12),NSO(12),QR1(12)
      INTEGER PBP(12),Q(12),QR(12),Q1(12),RLCONS(12),ROP(12),R2(12)
      REAL AC,AS1(12),A1,A2(12),C1(12),C2(12),D(12),DBAR(12),DLT(12)
      REAL DRTAT(12),E(12),G(12),GLT(12),GRTAT(12),H,LAMBDA(12),MQTRSL
      REAL PVAR(12),QW(12),QREOQ(12),RF(12),RISK(12)
      REAL RMAX(12),RMIN(12),ROPBAS(12),RRCT,R2BAS(12),SL(12),Z(12)
      CHARACTER*9 NIIN(12)
      CHARACTER*2 COG1(12),COG2(12),AUTHLV(12)
      CHARACTER*1 SLC(12),AAC(12),NIMSC(12)
*                                                                     *
***********************************************************************
*                                                                     *
*                        INITIALIZE VARIABLES                         *
*                                                                     *
***********************************************************************
* WE WILL ONLY COMPUTE THE DESIRED VALUES FOR 12 ITEMS                *
***********************************************************************
*                                                                     *
      N = 12
*                                                                     *
***********************************************************************
* THE ANNUAL HOLDING COST FOR REPAIRABLES IS 21¢ PER DOLLAR HELD.     *
***********************************************************************
*                                                                     *
      H = 0.21
*                                                                     *
***********************************************************************
* A1 AND AC ARE PERIODICALLY CHANGED.  CHECK WITH SPCC CODE 0412 AT   *
* A/V 430-4886 TO VERIFY THESE VALUES.                                *
***********************************************************************
*                                                                     *
      AC = 730.00
      A1 = 1730.00
*                                                                     *
***********************************************************************
* RRCT AND MQTRSL ARE PERIODICALLY CHANGED.  CALL SPCC CODE 04211 AT  *
* A/V 430-4894 TO VERIFY THESE VALUES.                                *
***********************************************************************
*                                                                     *
      RRCT   =  0.0
      MQTRSL = 20.0
*                                                                     *
***********************************************************************
* READ IN THE SPCC DATA FOR THE N ITEMS                               *
***********************************************************************
*                                                                     *
```

```
      DO 5 I = 1,N
      READ(10,1) COG1(I),COG2(I),NIIN(I),SLC(I),E(I),NRPR(I),C1(I),D(I),
     *           DBAR(I)
    1 FORMAT (2A,1X,A,1X,A,1X,F4.3,1X,I4,1X,F11.2,1X,F11.8,1X,F11.8)
      READ(10,2) G(I),PVAR(I),RF(I),AS1(I),DRTAT(I),C2(I)
    2 FORMAT (F11.8,1X,F14.8,1X,F11.8,1X,F9.0,1X,F11.2,1X,F11.2)
      READ(10,3)  A2(I),LOT(I),NSO(I),DSCNTQ(I),NIMSC(I),DLT(I),GLT(I)
    3 FORMAT (F9.0,1X,3(I8,1X),A,1X,F12.8,1X,F11.2)
      READ(10,4) GRTAT(I),AUTHLV(I),AAC(I)
    4 FORMAT (F11.2,1X,A,1X,A)
    5 CONTINUE
      DO 20 I = 1,N
      WRITE (6,6)COG1(I),COG2(I),NIIN(I),SLC(I),E(I),NRPR(I),C1(I),D(I),
     *           DBAR(I)
    6 FORMAT (1X,2A,1X,A,1X,A,1X,F4.3,1X,I4,1X,F11.2,1X,F11.8,1X,F11.8)
      WRITE (6,7)G(I),PVAR(I),RF(I),AS1(I),DRTAT(I),C2(I)
    7 FORMAT (1X,F11.8,1X,F14.8,1X,F11.8,1X,F9.0,1X,F11.2,1X,F11.2)
      WRITE (6,8)A2(I),LOT(I),NSO(I),DSCNTQ(I),NIMSC(I),DLT(I),GLT(I)
    8 FORMAT (1X,F9.0,1X,3(I8,1X),A,1X,F12.8,1X,F11.2)
      WRITE (6,9)GRTAT(I),AUTHLV(I),AAC(I)
    9 FORMAT (1X,F11.2,1X,A,1X,A)
   20 CONTINUE
*                                                                      *
************************************************************************
* THIS IS A LOOP TO CALCULATE THE PROCUREMENT PROBLEM VARIABLE (Z) FOR *
* N DATA ITEMS.  SEE FD-D01 P. O-41.                                   *
************************************************************************
*                                                                      *
      DO 10 I = 1,N
         Z(I) = DLT(I) - GLT(I) + GRTAT(I)
         IF (Z(I).LT.0.0) Z(I) = 0.0
         IF (Z(I).LE.0.) PVAR(I) = 0.
************************************************************************
* SPCC SPECIFIES ONLY ONE AAC, J,  ON THE LEVELS PARAMETER CARD.  IF   *
* THE ITEM'S AAC = J, SPCC WILL NOT STOCK THE ITEM.  SEE FMSO PS-D01DX *
* MANUAL, P. K-7, PARA 30-A.                                           *
************************************************************************
         IF (AAC(I).EQ.'J') PVAR(I) = 0.
   10 CONTINUE
*                                                                      *
************************************************************************
* THIS IS THE DRIVER PORTION OF THE PROGRAM.  MAJOR SUBROUTINES TO     *
* COMPUTE REORDER LEVEL, REORDER QUANTITY, REPAIR LEVEL, AND REPAIR    *
* QUANTITY ARE EXECUTED FROM HERE.                                     *
************************************************************************
*                                                                      *
      CALL COGVAL (COG1,COG2,N,NIIN,RMIN,RMAX,LAMBDA,PBP,RLCONS)
      CALL SHFLIF (SLC,N,SL)
      CALL WILEOQ (D,G,A1,AS1,H,C1,N,QW)
      CALL BASEOQ (D,G,DSCNTQ,N,QW,Q1)
      CALL RISKCP (C2,D,G,C1,DBAR,E,LAMBDA,RF,H,RMIN,RMAX,N,RISK)
      CALL ROPUNC (Z,PVAR,RISK,PBP,N,ROPBAS)
      CALL ROPCON (ROPBAS,NRPR,SL,D,G,Z,DSCNTQ,LOT,MQTRSL,N,NSO,RLCONS,
     *             AAC,ROP)
      CALL CONEOQ (LOT,D,G,SL,ROP,Z,N,AAC,Q1,Q)
      CALL RPQEOQ (AC,A2,D,G,H,C2,N,QREOQ)
```

```
      CALL BASRPQ (RRCT,G,QREOQ,N,QR1)
      CALL REPQTY (QR1,N,SL,D,G,ROPBAS,Z,LOT,DRTAT,NIMSC,AUTHLV,QR)
      CALL BRPROP (QR,N,Z,DRTAT,ROP,R2BAS)
      CALL REPROP (N,NRPR,D,SL,DRTAT,LOT,R2BAS,NSO,G,NIMSC,AUTHLV,R2)
      DO 15 I = 1,N
         WRITE (6,12) Q(I),ROP(I),QR(I),R2(I)
   12    FORMAT (1X,'Q= ',I8,3X,'ROP= ',I8,3X,'QR= ',I8,3X,'R2= ',I8)
   15 CONTINUE
      END
*                                                                     *
***********************************************************************
*                         COGVAL SUBROUTINE                           *
***********************************************************************
*                            DESCRIPTION                              *
***********************************************************************
*                                                                     *
* THIS SUBROUTINE USES THE 4 DIGIT COG TO GET THE VALUES FOR THE      *
* MINIMUM ALLOWABLE RISK (RMIN), MAXIMUM ALLOWABLE RISK (RMAX),       *
* SHORTAGE COST (LAMBDA), PROBABILITY BREAK POINT (PBP), AND REORDER  *
* LEVEL CONSTRAINT (RLCONST).  THE VALUES FOR RMIN, RMAX, LAMBDA, PBP, *
* AND RLCONST CHANGE PERIODICALLY.  CONTACT SPCC CODE 0412 AT A/V 430- *
* 4886 TO VERIFY THAT THESE VALUES ARE CURRENT.  THIS PROGRAM USES    *
* VALUES PUT OUT IN MARCH 1989 AND ARE CURRENT AS OF AUGUST 1989.     *
*                                                                     *
***********************************************************************
*                       VARIABLE DEFINITIONS                          *
***********************************************************************
*                                                                     *
      SUBROUTINE COGVAL (COG1,COG2,N,NIIN,RMIN,RMAX,LAMBDA,PBP,RLCONS)
*                                                                     *
***********************************************************************
*                       VARIABLE DECLARATIONS                         *
***********************************************************************
*                                                                     *
      REAL RMIN(N),RMAX(N),LAMBDA(N)
      INTEGER I,N,PBP(N),RLCONS(N)
      CHARACTER*2 COG1(N),COG2(N)
      CHARACTER*9 NIIN(N)
*                                                                     *
***********************************************************************
*                                                                     *
      DO 10 I = 1,N
         IF (COG1(I).EQ.'7G') THEN
            IF (COG2(I).EQ.'4A'.OR.COG2(I).EQ.'3A'.OR.COG2(I).EQ.'4D'
     *         .OR.COG2(I).EQ.'3D') THEN
               RMIN(I)    = 0.15
               RMAX(I)    = 0.40
               LAMBDA(I)  = 1500.
               PBP(I)     = 0
               RLCONS(I)  = 1
            ELSEIF(COG2(I).EQ.'2A'.OR.COG2(I).EQ.'1A'.OR.COG2(I).EQ.'0A'
     *         .OR.COG2(I).EQ.'2D'.OR.COG2(I).EQ.'1D'.OR.COG2(I).EQ.'0D'
     *)        THEN
               RMIN(I)    = 0.15
               RMAX(I)    = 0.40
               LAMBDA(I)  = 1000.
```

```
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF(COG2(I).EQ.'4B'.OR.COG2(I).EQ.'3B'.OR.COG2(I).EQ.'1B'
     *  .OR.COG2(I).EQ.'0B'.OR.COG2(I).EQ.'4E'.OR.COG2(I).EQ.'3E'
     *  .OR.COG2(I).EQ.'1E'.OR.COG2(I).EQ.'0E') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.40
        LAMBDA(I)   = 400.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF(COG2(I).EQ.'2B'.OR.COG2(I).EQ.'2E') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.40
        LAMBDA(I)   = 200.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF (COG2(I).EQ.'4C'.OR.COG2(I).EQ.'4F') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.50
        LAMBDA(I)   = 600.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF (COG2(I).EQ.'1C'.OR.COG2(I).EQ.'0C') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.99
        LAMBDA(I)   = 600.
        PBP(I)      = 20
        RLCONS(I)   = 0
      ELSEIF (COG2(I).EQ.'3C'.OR.COG2(I).EQ.'2C') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.50
        LAMBDA(I)   = 250.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF (COG2(I).EQ.'3F') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.50
        LAMBDA(I)   = 400.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF (COG2(I).EQ.'2F') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.50
        LAMBDA(I)   = 900.
        PBP(I)      = 0
        RLCONS(I)   = 1
      ELSEIF (COG2(I).EQ.'1F') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.99
        LAMBDA(I)   = 900.
        PBP(I)      = 20
        RLCONS(I)   = 0
      ELSEIF (COG2(I).EQ.'0F') THEN
        RMIN(I)     = 0.15
        RMAX(I)     = 0.99
        LAMBDA(I)   = 1200.
```

```
            PBP(I)     = 20
            RLCONS(I)  = 0
         ELSE
            WRITE (6,20) COG1(I),COG2(I),NIIN(I)
 20         FORMAT (1X,'THE 4 DIGIT COG: ',1X,A2,A2,1X,'FOR NIIN: ',1X,
     *           A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'7H') THEN
          IF (COG2(I).EQ.'4D'.OR.COG2(I).EQ.'3D'.OR.COG2(I).EQ.'2D'
     *      .OR.COG2(I).EQ.'1D') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 1500.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'4A'.OR.COG2(I).EQ.'3A'.OR.COG2(I).EQ.'2A'
     *      .OR.COG2(I).EQ.'1A'.OR.COG2(I).EQ.'0A') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 800.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'4E'.OR.COG2(I).EQ.'3E'.OR.COG2(I).EQ.'2E'
     *      .OR.COG2(I).EQ.'1E'.OR.COG2(I).EQ.'0E') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 200.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'4B'.OR.COG2(I).EQ.'3B'.OR.COG2(I).EQ.'2B'
     *      .OR.COG2(I).EQ.'0B') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 400.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'4F'.OR.COG2(I).EQ.'3F'.OR.COG2(I).EQ.'2F'
     *)     THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.50
            LAMBDA(I)  = 500.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'3C'.OR.COG2(I).EQ.'2C') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.50
            LAMBDA(I)  = 400.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'1C'.OR.COG2(I).EQ.'0C') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.99
            LAMBDA(I)  = 700.
            PBP(I)     = 20
            RLCONS(I)  = 0
         ELSEIF (COG2(I).EQ.'1B') THEN
```

```
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 725.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'N1') THEN
            RMIN(I)    = 0.15
            RMAX(I)    =.0.40
            LAMBDA(I)  = 1200.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'S1') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.50
            LAMBDA(I)  = 1200.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'4C') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.50
            LAMBDA(I)  = 700.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'1F') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.99
            LAMBDA(I)  = 100.
            PBP(I)     = 20
            RLCONS(I)  = 0
         ELSEIF (COG2(I).EQ.'0F') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.99
            LAMBDA(I)  = 500.
            PBP(I)     = 20
            RLCONS(I)  = 1
         ELSE
            WRITE (6,25) COG1(I),COG2(I),NIIN(I)
25          FORMAT (1X,'THE 4 DIGIT COG: ',1X,A2,A2,1X,'FOR NIIN: ',1X,
     *             A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'7E') THEN
          IF (COG2(I).EQ.'4A'.OR.COG2(I).EQ.'3A'.OR.COG2(I).EQ.'4D'
     *       .OR.COG2(I).EQ.'3D') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 1500.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'2A'.OR.COG2(I).EQ.'1A'.OR.COG2(I).EQ.'0A'
     *       .OR.COG2(I).EQ.'2D'.OR.COG2(I).EQ.'1D'.OR.COG2(I).EQ.'0D'
     *)         THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.40
            LAMBDA(I)  = 1000.
            PBP(I)     = 0
            RLCONS(I)  = 1
```

```
      ELSEIF(COG2(I).EQ.'4B'.OR.COG2(I).EQ.'3B'.OR.COG2(I).EQ.'1B'
*        .OR.COG2(I).EQ.'0B'.OR.COG2(I).EQ.'4E'.OR.COG2(I).EQ.'3E'
*        .OR.COG2(I).EQ.'1E'.OR.COG2(I).EQ.'0E'.OR.COG2(I).EQ.'4M'
*)       THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.40
         LAMBDA(I)  = 400.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF(COG2(I).EQ.'2M'.OR.COG2(I).EQ.'1M'.OR.COG2(I).EQ.'0M'
*)       THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.40
         LAMBDA(I)  = 600.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF(COG2(I).EQ.'2B'.OR.COG2(I).EQ.'2E') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.40
         LAMBDA(I)  = 200.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF(COG2(I).EQ.'4C'.OR.COG2(I).EQ.'4F') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.50
         LAMBDA(I)  = 600.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF (COG2(I).EQ.'3C'.OR.COG2(I).EQ.'2C') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.50
         LAMBDA(I)  = 250.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF (COG2(I).EQ.'1C'.OR.COG2(I).EQ.'0C') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.99
         LAMBDA(I)  = 600.
         PBP(I)     = 20
         RLCONS(I)  = 0
      ELSEIF (COG2(I).EQ.'3M') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.40
         LAMBDA(I)  = 100.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF (COG2(I).EQ.'3F') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.50
         LAMBDA(I)  = 400.
         PBP(I)     = 0
         RLCONS(I)  = 1
      ELSEIF (COG2(I).EQ.'2F') THEN
         RMIN(I)    = 0.15
         RMAX(I)    = 0.50
         LAMBDA(I)  = 900.
```

```
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF (COG2(I).EQ.'1F') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.99
            LAMBDA(I)  = 900.
            PBP(I)     = 20
            RLCONS(I)  = 0
         ELSEIF (COG2(I).EQ.'OF') THEN
            RMIN(I)    = 0.15
            RMAX(I)    = 0.99
            LAMBDA(I)  = 1200.
            PBP(I)     = 20
            RLCONS(I)  = 0
         ELSE
            WRITE (6,30) COG1(I),COG2(I),NIIN(I)
30          FORMAT (1X,'THE 4 DIGIT COG:',1X,A2,A2,1X,'FOR NIIN:',1X,
     *            A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'6A') THEN
          IF (COG2(I).EQ.'C1'.OR.COG2(I).EQ.'C2'.OR.COG2(I).EQ.'C3'
     *)     THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 6000.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'R1'.OR.COG2(I).EQ.'R2'.OR.COG2(I).EQ.'R3'
     *)     THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 50.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSE
            WRITE (6,35) COG1(I),COG2(I),NIIN(I)
35          FORMAT (1X,'THE 4 DIGIT COG:',1X,A2,A2,1X,'FOR NIIN:',1X,
     *            A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'6H') THEN
          IF (COG2(I).EQ.'C1'.OR.COG2(I).EQ.'C2'.OR.COG2(I).EQ.'C3'
     *)     THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 6000.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'R1'.OR.COG2(I).EQ.'R2'.OR.COG2(I).EQ.'R3'
     *)     THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 50.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSE
            WRITE (6,40) COG1(I),COG2(I),NIIN(I)
```

```
40          FORMAT (1X,'THE 4 DIGIT COG: ',1X,A2,A2,1X,'FOR NIIN: ',1X,
  *              A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'6X') THEN
          IF (COG2(I).EQ.'C1'.OR.COG2(I).EQ.'C2'.OR.COG2(I).EQ.'C3'
  *)        THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 2500.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSEIF(COG2(I).EQ.'R1') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 100.
            PBP(I)     = 0
            RLCONS(I)  = 1
          ELSEIF (COG2(I).EQ.'R2'.OR.COG2(I).EQ.'R3') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.35
            LAMBDA(I)  = 50.
            PBP(I)     = 0
            RLCONS(I)  = 1
         ELSE
            WRITE (6,45) COG1(I),COG2(I),NIIN(I)
45          FORMAT (1X,'THE 4 DIGIT COG: ',1X,A2,A2,1X,'FOR NIIN: ',1X,
  *              A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
         ENDIF
      ELSEIF (COG1(I).EQ.'7Z') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.45
            LAMBDA(I)  = 1200.
            PBP(I)     = 20
            RLCONS(I)  = 0
      ELSEIF (COG1(I).EQ.'6B') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.40
            LAMBDA(I)  = 100.
            PBP(I)     = 8
            RLCONS(I)  = 0
      ELSEIF (COG1(I).EQ.'6D') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.40
            LAMBDA(I)  = 100.
            PBP(I)     = 0
            RLCONS(I)  = 1
      ELSEIF (COG1(I).EQ.'6L') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.50
            LAMBDA(I)  = 400.
            PBP(I)     = 20
            RLCONS(I)  = 0
      ELSEIF (COG1(I).EQ.'6M') THEN
            RMIN(I)    = 0.01
            RMAX(I)    = 0.40
            LAMBDA(I)  = 50.
```

```
          PBP(I)      = 20
          RLCONS(I)  = 0
      ELSEIF (COG1(I).EQ.'6N') THEN
          RMIN(I)    = 0.01
          RMAX(I)    = 0.35
          LAMBDA(I)  = 100.
          PBP(I)     = 0
          RLCONS(I)  = 1
      ELSEIF (COG1(I).EQ.'8A') THEN
          RMIN(I)    = 0.01
          RMAX(I)    = 0.99
          LAMBDA(I)  = 0.03
          PBP(I)     = 20
          RLCONS(I)  = 0
      ELSE
          WRITE (6,50) COG1(I),COG2(I),NIIN(I)
   50     FORMAT (1X,'THE 4 DIGIT COG: ',1X,A2,A2,1X,'FOR NIIN: ',1X,
     *          A9,1X,'IS NOT DEFINED IN THE COGVALUE SUBROUTINE.')
      ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                         *
***************************************************************************
*                          SHFLIF SUBROUTINE                              *
***************************************************************************
*                             DESCRIPTION                                 *
***************************************************************************
*                                                                         *
* THIS SUBROUTINE CONVERTS THE SHELF LIFE CODE (SLC) (DEN C028) INTO      *
* QUARTERS (SL).  THE SHELF LIFE IN QUARTERS IS THEN USED WHEN            *
* COMPUTING THE CONSTRAINED ORDER QUANTITY, CONSTRAINED REORDER LEVEL,    *
* CONSTRAINED REPAIR QUANTITY, AND THE CONSTRAINED REPAIR LEVEL.          *
*                                                                         *
***************************************************************************
*                         VARIABLE DEFINITIONS                            *
***************************************************************************
*                                                                         *
* SLC = SHELF LIFE CODE.  A CHARACTER VARIABLE THAT MUST BE CONVERTED     *
*       TO QUARTERS FOR USE IN OTHER PARTS OF THE PROGRAM.                *
* SL  = SHELF LIFE.  A REAL VARIABLE THAT REPRESENTS THE SHELF LIFE IN    *
*       QUARTERS.                                                         *
***************************************************************************
*                                                                         *
      SUBROUTINE SHFLIF (SLC,N,SL)
***************************************************************************
*                         VARIABLE DECLARATIONS                           *
***************************************************************************
*                                                                         *
      CHARACTER*1 SLC(N)
      REAL SL(N)
      INTEGER N
*                                                                         *
***************************************************************************
*
* IF THE ITEM HAS NO SHELF LIFE, MAKE SL VERY LARGE SO THAT IT PLAYS      *
```

```
* NO PART IN DETERMINING CONSTRAINED QUANTITIES OR REORDER LEVELS.      *
*                                                                      *
************************************************************************
*                                                                      *
      DO 10 I = 1,N
         IF (SLC(I).EQ.'0') THEN
            SL(I) = 9999.
************************************************************************
*                                                                      *
* OTHERWISE, ASSIGN THE SL AS APPROPRIATE.                             *
*                                                                      *
************************************************************************
         ELSEIF (SLC(I).EQ.'A') THEN
            SL(I) = 1./3.
         ELSEIF (SLC(I).EQ.'B') THEN
            SL(I) = 2./3.
         ELSEIF (SLC(I).EQ.'C'.OR.SLC(I).EQ.'1') THEN
            SL(I) = 1.
         ELSEIF (SLC(I).EQ.'D') THEN
            SL(I) = 4./3.
         ELSEIF (SLC(I).EQ.'E') THEN
            SL(I) = 5./3.
         ELSEIF (SLC(I).EQ.'F'.OR.SLC(I).EQ.'2') THEN
            SL(I) = 2.
         ELSEIF (SLC(I).EQ.'G'.OR.SLC(I).EQ.'3') THEN
            SL(I) = 3.
         ELSEIF (SLC(I).EQ.'H'.OR.SLC(I).EQ.'4') THEN
            SL(I) = 4.
         ELSEIF (SLC(I).EQ.'J') THEN
            SL(I) = 5.
         ELSEIF (SLC(I).EQ.'K'.OR.SLC(I).EQ.'5') THEN
            SL(I) = 6.
         ELSEIF (SLC(I).EQ.'L') THEN
            SL(I) = 7.
         ELSEIF (SLC(I).EQ.'M'.OR.SLC(I).EQ.'6') THEN
            SL(I) = 8.
         ELSEIF (SLC(I).EQ.'N') THEN
            SL(I) = 9.
         ELSEIF (SLC(I).EQ.'P') THEN
            SL(I) = 10.
         ELSEIF (SLC(I).EQ.'Q'.OR.SLC(I).EQ.'7') THEN
            SL(I) = 12.
         ELSEIF (SLC(I).EQ.'R'.OR.SLC(I).EQ.'8') THEN
            SL(I) = 16.
         ELSEIF (SLC(I).EQ.'S'.OR.SLC(I).EQ.'9') THEN
            SL(I) = 20.
*                                                                      *
************************************************************************
*
* IF THE ITEM HAS SHELF LIFE CODE X (SL > 60 MONTHS), MAKE SL 7 YEARS. *
* MY EXPERIENCE WITH MOST OF THESE ITEMS IS THAT THE SHELF LIFE IS     *
* ABOUT 7 YEARS.                                                       *
*                                                                      *
************************************************************************
*                                                                      *
         ELSEIF (SLC(I).EQ.'X') THEN
```

```
          SL(I) = 84.
*                                                                        *
**************************************************************************
*                                                                        *
* IF THE ITEM HAS AN UNDEFINED SHELF LIFE CODE, ASSUME IT IS GARBAGE    *
* AND MAKE THE SL SO LARGE THAT IT WILL PLAY NO PART IN DETERMINING THE*
* CONSTRAINED REORDER QUANTITIES OR CONSTRAINED REORDER LEVELS.         *
*                                                                        *
**************************************************************************
*                                                                        *
        ELSE
          SL(I) = 9999.
        ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                        *
**************************************************************************
*                          WILEOQ SUBROUTINE                             *
**************************************************************************
*                             DESCRIPTION                                *
**************************************************************************
*                                                                        *
* THIS SUBROUTINE COMPUTES THE WILSON EOQ PROCUREMENT QUANTITY MODIFIED*
* FOR REGENERATIONS (NO DEN).  SEE FD-D01 P. O-23.                      *
*                                                                        *
**************************************************************************
*                        VARIABLE DEFINITIONS                            *
**************************************************************************
*                                                                        *
**************************************************************************
*                                                                        *
      SUBROUTINE WILEOQ(D,G,A1,AS1,H,C1,N,QW)
*                                                                        *
**************************************************************************
*                        VARIABLE DECLARATIONS                           *
**************************************************************************
*                                                                        *
      REAL D(N),G(N),A1,AS1(N),H,C1(N),QW(N)
      INTEGER I,N
*                                                                        *
**************************************************************************
*                                                                        *
      DO 10 I = 1,N
         QW(I) = SQRT((8.*(D(I) - G(I)) * (A1 + AS1(I))) / (H * C1(I)))
   10 CONTINUE
      RETURN
      END
*                                                                        *
**************************************************************************
*                          BASEOQ SUBROUTINE                             *
**************************************************************************
*                             DESCRIPTION                                *
**************************************************************************
*                                                                        *
* THIS SUBROUTINE COMPUTES THE BASIC PROCUREMENT ORDER QUANTITY(NO DEN)*
```

```
* SEE FD-D01 P. O-23.                                                   *
*                                                                       *
*************************************************************************
*                        VARIABLE DEFINITIONS                           *
*************************************************************************
*                                                                       *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                       *
* Q2 = ATTRITION DEMAND * DISCOUNT QUANTITY                             *
* Q3 = MAXIMUN OF Q2 AND THE WILSON EOQ VALUE (QW).                     *
* Q4 = 12 QUARTERS OR 3 YEARS OF ATTRITION DEMAND.                      *
*                                                                       *
*************************************************************************
*                                                                       *
      SUBROUTINE BASEOQ(D,G,DSCNTQ,N,QW,Q1)
*                                                                       *
*************************************************************************
*                        VARIABLE DECLARATIONS                          *
*************************************************************************
*                                                                       *
      REAL D(N),G(N),QW(N),Q2,Q3,Q4
      INTEGER I,N,DSCNTQ(N),Q1(N)
*                                                                       *
*************************************************************************
*                                                                       *
      DO 10 I = 1,N
         IF (DSCNTQ(I).EQ.0) DSCNTQ(I) = 1
         IF (D(I).LE.G(I)) THEN
            Q1(I) = 1
         ELSE
            Q2 = DSCNTQ(I) * (D(I) - G(I))
            Q3 = AMAX1(QW(I),Q2)
            Q4 = 12. * (D(I) - G(I))
            Q4 = AMIN1(Q3,Q4)
            Q1(I) = IFIX (Q4 + .999)
         ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                       *
*************************************************************************
*                         RISKCP SUBROUTINE                             *
*************************************************************************
*                            DESCRIPTION                                *
*************************************************************************
*                                                                       *
* THIS SUBROUTINE COMPUTES THE PROCUREMENT STOCKOUT RISK FOR THE        *
* INTEGRATED REPAIRABLES MODEL. SEE FD-D01 PP.O-26 THRU O-27 (NO DEN).  *
*                                                                       *
*************************************************************************
*
      SUBROUTINE RISKCP (C2,D,G,C1,DBAR,E,LAMBDA,RF,H,RMIN,RMAX,N,RISK)
*
*************************************************************************
*                        VARIABLE DEFINITIONS                           *
*************************************************************************
*                                                                       *
```

```
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                         *
* C3      = THE INTEGRATED COST USED IN THE RISK EQUATION.  IT IS A     *
*           WEIGHTED COST WITH TWO ELEMENTS:  REPAIR COST (C2) AND       *
*           PROCUREMENT COST (C1).                                        *
* TRISK   = RISK VALUE FOR THE INTEGRATED DLR MODEL.                      *
* VRISK   = VARIABLE PROCUREMENT STOCKOUT RISK.                           *
* ARISK   = ACCEPTABLE PROCUREMENT STOCKOUT RISK.                         *
*                                                                         *
***************************************************************************
*                         VARIABLE DECLARATIONS                           *
***************************************************************************
*                                                                         *
      REAL C2(N),D(N),G(N),C1(N),DBAR(N),E(N),LAMBDA(N),RF(N),RMIN(N),
     * RMAX(N),RISK(N),C3,H,VRISK,TRISK,ARISK
      INTEGER N,I
*                                                                         *
***************************************************************************
*                                                                         *
      DO 10 I = 1,N
*                                                                         *
***************************************************************************
* THIS PORTION IS ON P. 0-26.  IT IS THE VARIABLE PROCUREMENT STOCKOUT *
* RISK.                                                                   *
***************************************************************************
*                                                                         *
         IF (G(I).GT.D(I))  G(I)    = D(I)
         IF (DBAR(I).EQ.0.) DBAR(I) = 1.
         IF (RF(I).EQ.0.)   RF(I)   = 1.
         IF (E(I).EQ.0.)    E(I)    = 0.5
         C3    = C2(I)*(G(I)/D(I)) + C1(I)*(1-(G(I)/D(I)))
         TRISK = (H*C3*DBAR(I)) / (RF(I)*LAMBDA(I)*E(I))
         VRISK = AMIN1(999999.,TRISK)
*                                                                         *
***************************************************************************
* THIS PORTION IS ON P. 0-27.  IT IS THE ACCEPTABLE PROCUREMENT STOCKOUT
* RISK.                                                                   *
***************************************************************************
* THIS CHECK WAS NOT IN ANY PROGRAM FUNCTIONAL OR DETAIL SPECFICATION, *
* BUT WAS IN FMSO'S LEVELS PROGRAM.  LOOK AT THE FORTRAN SECTION OF THE*
* PROGRAM LINE 1650.                                                      *
***************************************************************************
*                                                                         *
         IF (D(I).LE.0.) THEN
            ARISK = 0.0
         ELSE
            ARISK = VRISK / (VRISK + 1.)
         ENDIF
*                                                                         *
***************************************************************************
*                                                                         *
         RISK(I) = AMAX1(ARISK,RMIN(I))
         RISK(I) = AMIN1(RISK(I),RMAX(I))
   10 CONTINUE
      RETURN
      END
*                                                                         *
```

```
************************************************************************
*                         ROPUNC SUBROUTINE                            *
************************************************************************
*                            DESCRIPTION                               *
************************************************************************
*                                                                      *
* SUBROUTINE TO FIND THE UNCONSTRAINED REORDER POINT (ROPBASIC).  WE   *
* COMPARE THE PROCUREMENT PROBLEM VARIABLE (Z) WITH AN ICP SPECIFIED   *
* PROBABILITY BREAK POINT (PBP OR PB) TO DECIDE IF WE WILL USE THE     *
* NORMAL DISTRIBUTION OR THE NEGATIVE BINOMIAL DISTRIBUTION TO COMPUTE *
* THE ROPBASIC.  IF Z >= BP, WE USE THE NORMAL DISTRIBUTION.  IF Z < BP*
* WE USE THE NEGATIVE BINOMIAL DISTRIBUTION.  I USE AN IMSL FUNCTION,  *
* ANORIN, TO RETURN THE NORMAL(0,1) VALUE (ZVALUE) AND THE SUBROUTINE, *
* NEGBINOM, TO CALCULATE THE ROPBASIC USING THE NEGATIVE BINOMIAL      *
* DISTRIBUTION.                                                        *
*                                                                      *
************************************************************************
*                       VARIABLE DEFINITIONS                           *
************************************************************************
*                                                                      *
* ALL VARIABLES HAVE BEEN PREVIOUSLY DEFINED EXCEPT FOR:               *
* BP       = REAL VARIABLE THAT HOLDS THE ICP SPECIFIED PROBABILITY    *
*              BREAK POINT.                                            *
* SERVLV   = SERVICE LEVEL.  THIS IS THE PROBABILITY OF NO STOCKOUTS.  *
* ZVALUE   = STANDARD NORMAL RANDOM VARIABLE Z.  ANORIN(SERVLEVL)      *
*              RETURNS THIS VALUE.                                     *
*                                                                      *
************************************************************************
*                                                                      *
      SUBROUTINE ROPUNC (Z,PVAR,RISK,PBP,N,ROPBAS)
*                                                                      *
************************************************************************
*                       VARIABLE DECLARATIONS                          *
************************************************************************
*                                                                      *
      REAL Z(N),PVAR(N),RISK(N),BP(12),SERVLV(12),ZVALUE(12),ROPBAS(N)
      INTEGER I,N,PBP(N)
      DO 10 I = 1,N
         BP(I) = FLOAT(PBP(I))
         SERVLV(I) = 1.- RISK(I)
         IF (Z(I).GE.BP(I)) THEN
            IF (RISK(I).EQ.0.5) THEN
               ROPBAS(I) = Z(I)
            ELSEIF (RISK(I).GT.0.5) THEN
               ZVALUE(I)   = ANORIN (SERVLV(I))
               ROPBAS(I) = Z(I) - ZVALUE(I) * SQRT(PVAR(I))
            ELSE
               ZVALUE(I)   = ANORIN (SERVLV(I))
               ROPBAS(I) = Z(I) + ZVALUE(I) * SQRT(PVAR(I))
            ENDIF
         ELSE
            CALL NEGBIN  (Z(I),PVAR(I),RISK(I),SERVLV(I),ROPBAS(I))
         ENDIF
   10 CONTINUE
      RETURN
```

```
      END
*                                                                          *
****************************************************************************
*                         NEGBIN SUBROUTINE                                *
****************************************************************************
*                            DESCRIPTION                                   *
****************************************************************************
*                                                                          *
* SUBROUTINE TO FIND THE MIN X SUCH THAT THE CDF F(X).GE.(1-RISK).  IN *
* OTHER WORDS, X STARTS AT ZERO AND WE USE THE NEGATIVE BINOMIAL       *
* EQUATION TO CALCULATE THE PROBABILITY OF X=0, P(X=0).  WE COMPARE THE*
* VALUE OF P(X) TO OUR DESIRED SERVICE LEVEL (1-RISK = 1-PROB(STOCKOUT)*
* = PROB(NO STOCKOUT)).  IF P(X=0) >= SERVICE LEVEL, THEN THE          *
* UNCONSTRAINED REORDER LEVEL IS 0.  IF P(X=0) < SERVICE LEVEL, THEN WE*
* COMPUTE P(X=1).  WE SUM P(0) AND P(1) AND COMPARE THIS VALUE TO OUR  *
* SERVICE LEVEL.  WE CONTINUE UNTIL WE GET OUR SUM OF P(X)'S >= SERVICE*
* LEVEL.  THE NEG. BINOMIAL RECURRISION FORMULA IS USED.  THE FORMULA  *
* IS:                                                                  *
*                      P(X=0) = (RHO)**K                               *
*                      P(X)   = [(X+K-1)/X]*(1-RHO)*P(X-1)             *
*                      WHERE                                           *
*                         RHO = Z/PVAR                                 *
*                         K   = (Z**2)/(PVAR-Z)                        *
*                                                                      *
****************************************************************************
*                       VARIABLE DEFINITIONS                               *
****************************************************************************
*                                                                      *
* ALL VARIABLES HAVE BEEN PREVIOUSLY DEFINED EXCEPT FOR:               *
* ZZ        = PROCUREMENT PROBLEM VARIABLE (FANCY NAME FOR LEAD TIME   *
*             DEMAND)                                                  *
* PPVAR     = PROCUREMENT LEAD TIME VARIANCE.                          *
* RSK       = RISK.  SAME AS IN THE ROPUNCON SUBROUTINE.               *
* SRVLVL    = SERVICE LEVEL.  SAME AS IN THE ROPUNCON SUBROUTINE.      *
* ROPBS     = UNCONSTRAINED REORDER POINT.                             *
* ZVAL      = SAME AS ZVALUE IN THE ROPUNCON SUBROUTINE.               *
* SMPOFX    = SUMMATION OF P(X).                                       *
* X         = RANDOM VARIABLE IN THE NEGATIVE BINOMIAL FORMULA.        *
* RHO       = PROCUREMENT PROBLEM VARIABLE (Z OR ZZ) / PROCUREMENT LEAD *
*             TIME VARIANCE (PVAR OR PPVAR).                           *
* VTMRT     = VARIANCE TO MEAN RATIO TEST.  SPCC CALCULATES THE VARIANCE*
*             TO MEAN RATIO (PPVAR/ZZ) AND LATER USES IT TO DO A TEST TO*
*             SEE IF THEY REALLY WANT TO USE THE NORMAL DISTRIBUTION.  *
* R         = 1 - RHO.  VARIABLE USED TO SIMPLIFY THE FORMULAS.        *
* K         = (ZZ**2)/(PPVAR-ZZ).  ALSO PART OF THE RECURRSION FORMULA. *
* POFX      = P(X).                                                    *
* B         = X-1.  VARIABLE USED TO SIMPLIFY FORMULAS AND CONVERT X TO *
*             A REAL NUMBER.                                           *
*                                                                      *
* NOTE:  THIS SUBROUTINE USES A GOTO STATEMENT TO ACCOMPLISH WHAT A DO *
* WHILE STATEMENT WOULD.  FORTRAN 77 DOESN'T HAVE A DO WHILE COMMAND.  *
*                                                                      *
****************************************************************************
*                                                                          *
      SUBROUTINE NEGBIN (ZZ,PPVAR,RSK,SRVLVL,ROPBS)
*                                                                          *
```

```
*****************************************************************************
*                         VARIABLE DECLARATIONS                             *
*****************************************************************************
*                                                                           *
      REAL SMPOFX,RHO,ZZ,PPVAR,R,K,POFX,SRVLVL,ZVAL,VTMRT,RSK,ROPBS
      INTEGER X
*                                                                           *
*****************************************************************************
*                                                                           *
      SMPOFX = 0.
      X      = 0
      RHO    = ZZ/PPVAR
      R      = 1. - RHO
      VTMRT  = AMAX1 (1.01,PPVAR/ZZ)
      K      = (ZZ**2)/(PPVAR-ZZ)
      POFX   = RHO**K
      SMPOFX = POFX
   10 IF (K * LOG (VTMRT).GT.6.9.OR.POFX.LE.0.0001) THEN
         IF (RSK.EQ.0.5) THEN
            ROPBS = ZZ
         ELSEIF (RSK.GT.0.5) THEN
            ZVAL  = ANORIN (SRVLVL)
            ROPBS = ZZ - ZVAL * SQRT(PPVAR)
         ELSE
            ZVAL  = ANORIN (SRVLVL)
            ROPBS = ZZ + ZVAL * SQRT(PPVAR)
         ENDIF
      ELSEIF (SMPOFX.GT.SRVLVL) THEN
         ROPBS  = FLOAT (X)
      ELSE
         X      = X + 1
         B      = FLOAT (X-1)
         POFX   = (POFX * R * (B + K)) / FLOAT (X)
         SMPOFX = SMPOFX + POFX
         GOTO 10
      ENDIF
      RETURN
      END
*                                                                           *
*****************************************************************************
*                           ROPCON SUBROUTINE                               *
*****************************************************************************
*                              DESCRIPTION                                  *
*****************************************************************************
*                                                                           *
* THIS SUBROUTINE COMPUTES THE CONSTRAINED PROCUREMENT REORDER POINT.      *
* (DEN B019) SEE FD-D01 P. O-44 AND PS-D01DX P. K-7 AND L-1.               *
*                                                                           *
*****************************************************************************
*                                                                           *
      SUBROUTINE ROPCON (ROPBAS,NRPR,SL,D,G,Z,DSCNTQ,LOT,MQTRSL,N,NSO,
     *                   RLCONS,AAC,ROP)
*                                                                           *
*****************************************************************************
*                         VARIABLE DEFINITIONS                              *
*****************************************************************************
```

```
*                                                                          *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                          *
* MSLROP = REORDER POINT BASED ON THE MAX # QUARTERS OF SAFETY STOCK.      *
* SLROP  = REORDER POINT CONSTRAINED BY THE SHELF LIFE.                    *
* MAXROP = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED REORDER PT.      *
* R      = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED REORDER PT.      *
* R1     = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED REORDER PT.      *
*                                                                          *
****************************************************************************
*                        VARIABLE DECLARATIONS                             *
****************************************************************************
*                                                                          *
      REAL ROPBAS(N),MAXROP,SL(N),SLROP,D(N),G(N),Z(N),R,R1,MQTRSL,
     *     MSLROP
      INTEGER I,N,DSCNTQ(N),RLCONS(N),NRPR(N),LOT(N),NSO(N),ROP(N)
      CHARACTER*1 AAC(N)
*                                                                          *
****************************************************************************
*                                                                          *
      DO 10 I = 1,N
         IF (DSCNTQ(I).EQ.0) DSCNTQ(I) = 1
         IF (LOT(I).NE.0.OR.AAC(I).EQ.'J') THEN
            ROP(I) = 0
         ELSEIF (Z(I).LE.0.) THEN
            ROP(I) = MAX0 (NSO(I),0)
         ELSE
            MAXROP = AMAX1 (ROPBAS(I),FLOAT(NRPR(I)))
            IF (SL(I).EQ.9999.) THEN
               SLROP = MAXROP
            ELSE
               SLROP = 4.* D(I) * SL(I) + Z(I) - (D(I)-G(I)) *
     *                                           FLOAT(DSCNTQ(I))
            ENDIF
            MSLROP = MQTRSL*D(I) + Z(I)
            R1     = AMIN1 (SLROP,MAXROP,MSLROP)
            R      = AMAX1 (R1,FLOAT(NSO(I)),RLCONS(I)*Z(I),0.)
            ROP(I) = IFIX (R + 0.999)
         ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                          *
****************************************************************************
*                         CONEOQ SUBROUTINE                                *
****************************************************************************
*                            DESCRIPTION                                   *
****************************************************************************
*                                                                          *
* THIS SUBROUTINE COMPUTES THE CONSTRAINED PROCUREMENT ORDER QUANTITY.     *
* (DEN B021) SEE FD-D01 P. 0-46.                                           *
*                                                                          *
****************************************************************************
*                                                                          *
      SUBROUTINE CONEOQ (LOT,D,G,SL,ROP,Z,N,AAC,Q1,Q)
*                                                                          *
****************************************************************************
```

```
*                        VARIABLE DEFINITIONS                            *
**************************************************************************
*                                                                        *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                        *
* QSL = ORDER QUANTITY CONSTRAINED BY SHELF LIFE.                        *
* Q5  = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED ORDER QUANTITY.   *
*                                                                        *
**************************************************************************
*                        VARIABLE DECLARATIONS                           *
**************************************************************************
*
      REAL D(N),G(N),SL(N),Z(N),QSL,Q5
      INTEGER LOT(N),N,I,ROP(N),Q(N),Q1(N)
      CHARACTER*1 AAC(N)
*                                                                        *
**************************************************************************
*                                                                        *
      DO 10 I = 1,N
         IF (LOT(I).NE.0) THEN
            Q(I) = LOT(I)
         ELSEIF (D(I).LE.G(I).OR.AAC(I).EQ.'J'.OR.Z(I).LE.0.) THEN
            Q(I) = 1
         ELSE
            QSL  = 4.*SL(I)*(D(I)-G(I)) - AMAX1(0.,(FLOAT(ROP(I))-Z(I)))
            Q5   = AMIN1(QSL,FLOAT(Q1(I)))
            Q(I) = IFIX (Q5 + .999)
         ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                        *
**************************************************************************
*                         RPQEOQ SUBROUTINE                              *
**************************************************************************
*                            DESCRIPTION                                 *
**************************************************************************
*                                                                        *
* THIS SUBROUTINE COMPUTES THE UNCONSTRAINED REPAIR QUANTITY.            *
* (NO DEN).  SEE FD-D01 P. O-16.                                         *
*                                                                        *
**************************************************************************
*                                                                        *
      SUBROUTINE RPQEOQ (AC,A2,D,G,H,C2,N,QREOQ)
*                                                                        *
**************************************************************************
*                        VARIABLE DEFINITIONS                            *
**************************************************************************
*                                                                        *
* ALL VARIABLES WERE PREVIOUSLY DEFINED.                                 *
*                                                                        *
**************************************************************************
*                        VARIABLE DECLARATIONS                           *
**************************************************************************
*                                                                        *
      REAL AC,QREOQ(N),A2(N),D(N),G(N),H,C2(N)
```

```
      INTEGER I,N
*                                                                       *
*************************************************************************
*                                                                       *
      DO 10  I = 1,N
*
*************************************************************************
* CHECK C2 TO AVOID A ZERO DEVIDE PROBLEM.                              *
*************************************************************************
*
         IF (C2(I).EQ.0.) THEN
            C2(I) = 0.01
         ELSE
            QREOQ(I) = SQRT (8.*(AC+A2(I))*AMIN1(D(I),G(I)) / (H*C2(I)))
         ENDIF
   10 CONTINUE
      RETURN
      END
*                                                                       *
*************************************************************************
*                           BASRPQ SUBROUTINE                           *
*************************************************************************
*                              DESCRIPTION                              *
*************************************************************************
*                                                                       *
* THIS SUBROUTINE COMPUTES THE BASIC REPAIR QUANTITY (NO DEN).          *
* SEE FD-D01 P. O-16 AND PS-D01DX P. L-2.                               *
*                                                                       *
*************************************************************************
*                                                                       *
      SUBROUTINE BASRPQ (RRCT,G,QREOQ,N,QR1)
*                                                                       *
*************************************************************************
*                         VARIABLE DEFINITIONS                          *
*************************************************************************
*                                                                       *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                       *
* QR2 = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED REPAIR QUANTITY.*
* QR3 = TEMPORARY HOLDING VARIABLE FOR THE CONSTRAINED REPAIR QUANTITY.*
*                                                                       *
*************************************************************************
*                         VARIABLE DECLARATIONS                         *
*************************************************************************
*                                                                       *
      REAL RRCT,G(N),QR2,QR3,QREOQ(N)
      INTEGER I,N,QR1(N)
*                                                                       *
*************************************************************************
*                                                                       *
      DO 10   I  = 1,N
         QR2     = RRCT * G(I)
         QR3     = AMAX1 (1.,QREOQ(I),QR2)
         QR1(I)  = IFIX(QR3 + .999)
   10 CONTINUE
      RETURN
```

```
      END
*                                                                            *
******************************************************************************
*                          REPQTY SUBROUTINE                                 *
******************************************************************************
*                             DESCRIPTION                                    *
******************************************************************************
*                                                                            *
* THIS SUBROUTINE COMPUTES THE CONSTRAINED REPAIR QUANTITY (DEN B021A).*
* SEE FD-D01 P. O-57.  AGAIN, WE ARE USING THE INTEGRATED DLR MODEL.   *
*                                                                            *
******************************************************************************
*                                                                            *
      SUBROUTINE REPQTY(QR1,N,SL,D,G,ROPBAS,Z,LOT,DRTAT,NIMSC,AUTHLV,QR)
*                                                                            *
******************************************************************************
*                         VARIABLE DEFINITIONS                               *
******************************************************************************
*                                                                            *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                            *
* QSL   = REPAIR QUANTITY CONSTRAINED BY SHELF LIFE.                         *
* QLOT  = REPAIR QUANTITY IF THERE IS A LIFE OF TYPE QUANTITY.               *
* Q2MIN = TEMPORARY VARIABLE TO HOLD THE CONSTRAINED REPAIR QUANTITY.        *
* Q2    = TEMPORARY VARIABLE TO HOLD THE CONSTRAINED REPAIR QUANTITY.        *
*                                                                            *
******************************************************************************
*                         VARIABLE DECLARATIONS                              *
******************************************************************************
      REAL SL(N),QSL,D(N),G(N),Z(N),QLOT,DRTAT(N),Q2MIN,Q2,
     *     ROPBAS(N)
      INTEGER I,N,LOT(N),QR1(N),QR(N)
      CHARACTER*2 AUTHLV(N)
      CHARACTER*1 NIMSC (N)
*                                                                            *
******************************************************************************
*                                                                            *
      DO 10 I = 1,N
*                                                                            *
******************************************************************************
* THIS IS A CHECK TO SEE IF SPCC IS THE SECONDARY INVENTORY CONTROL          *
* ACTIVITY (SICA).  SEE P. 3-44 AND O-57 OF THE FMSO FD-D01 MANUAL.          *
* ALSO SEE FS-D01DX P. K-11, PARA. 38-A.                                     *
******************************************************************************
*                                                                            *
         IF (NIMSC(I).EQ.'5'.OR.NIMSC(I).EQ.'6'.AND.AUTHLV(I).EQ.'8D')
     *   THEN
            QR(I) = 0
*                                                                            *
******************************************************************************
* SEE P. K-11, PARA. 38-B OF THE FMSO FS-D01DX MANUAL FOR THE NEXT 2         *
* LINES.                                                                     *
******************************************************************************
*                                                                            *
         ELSEIF (D(I).EQ.0.0.OR.G(I).EQ.0.0.OR.DRTAT(I).EQ.0.) THEN
            QR(I) = 1
         ELSE
```

```
            QSL    = 4.*D(I)*SL(I)-AMAX1(0.0,(ROPBAS(I)-Z(I)))
            IF (LOT(I).NE.0) THEN
               QLOT  = FLOAT(LOT(I)) - DRTAT(I) -
     *                                   AMAX1(0.,(ROPBAS(I)-Z(I)))
               Q2MIN = AMIN1 (FLOAT(QR1(I)),QSL,QLOT)
            ELSE
               Q2MIN = AMIN1 (FLOAT(QR1(I)),QSL)
            ENDIF
            Q2    = AMAX1 (1.,Q2MIN)
            QR(I) = IFIX (Q2 + .999)
         ENDIF
 10   CONTINUE
         RETURN
         END
*                                                                        *
**************************************************************************
*                          BRPROP SUBROUTINE                             *
**************************************************************************
*                             DESCRIPTION                                *
**************************************************************************
*                                                                        *
* THIS SUBROUTINE COMPUTES THE BASIC REPAIR REORDER POINT OR LEVEL.       *
* SEE FD-D01 P. 0-53.  AGAIN, WE ARE USING THE INTEGRATED DLR MODEL.     *
* (NO DEN)                                                               *
*                                                                        *
**************************************************************************
*                                                                        *
      SUBROUTINE BRPROP (QR,N,Z,DRTAT,ROP,R2BAS)
*                                                                        *
**************************************************************************
*                         VARIABLE DEFINITIONS                           *
**************************************************************************
*                                                                        *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                        *
* RROP = ROP CONVERTED TO A REAL NUMBER FOR CALCULATIONS.                *
* RQR  = QR CONVERTED TO A REAL NUMBER FOR CALCULATIONS.                 *
*                                                                        *
**************************************************************************
*                         VARIABLE DECLARATIONS                          *
**************************************************************************
*                                                                        *
      REAL Z(N),DRTAT(N),R2BAS(N),RROP,RQR
      INTEGER I,N,ROP(N),QR(N)
*                                                                        *
**************************************************************************
*                                                                        *
      DO 10 I = 1,N
         RROP = FLOAT (ROP(I))
         RQR  = FLOAT (QR(I))
         R2BAS(I) = DRTAT(I) + AMAX1 ((RROP-Z(I)),0.0)
 10   CONTINUE
      RETURN
      END
*                                                                        *
**************************************************************************
*                          REPROP SUBROUTINE                             *
```

```
***************************************************************************
*                           DESCRIPTION                                   *
***************************************************************************
*                                                                         *
* THIS SUBROUTINE COMPUTES THE CONSTRAINED REPAIR REORDER POINT OR        *
* LEVEL (DEN B019B).  SEE FD-D01 P. 0-54.  AGAIN, WE ARE USING THE        *
* INTEGRATED DLR MODEL.                                                   *
*                                                                         *
***************************************************************************
*                                                                         *
      SUBROUTINE REPROP (N,NRPR,D,SL,DRTAT,LOT,R2BAS,NSO,G,NIMSC,AUTHLV,
     *                   R2)
*                                                                         *
***************************************************************************
*                       VARIABLE DEFINITIONS                              *
***************************************************************************
*                                                                         *
* ALL VARIABLES ARE AS DEFINED BEFORE EXCEPT FOR:                         *
* R2MAX = INITIAL CONSTRAINED REPAIR LEVEL.                               *
* R2SL  = REPAIR LEVEL CONSTRAINED BY SHELF LIFE.                         *
* R2MIN = TEMPORARY VARIABLE TO HOLD THE CONSTRAINED REPAIR LEVEL.        *
* RR2   = R2 CHANGED TO A REAL NUMBER FOR COMPUTATIONS.                   *
*                                                                         *
***************************************************************************
*                       VARIABLE DECLARATIONS                             *
***************************************************************************
*
      REAL DRTAT(N),D(N),SL(N),R2BAS(N),G(N),RR2,R2MAX,R2SL,R2MIN
      INTEGER I,N,LOT(N),NRPR(N),NSO(N),R2(N)
      CHARACTER*2 AUTHLV(N)
      CHARACTER*1 NIMSC (N)
*                                                                         *
***************************************************************************
*                                                                         *
      DO 10 I = 1,N
*                                                                         *
***************************************************************************
* THIS IS A CHECK TO SEE IF SPCC IS THE SECONDARY INVENTORY CONTROL       *
* ACTIVITY (SICA).  SEE P. 3-44 AND 0-54 OF THE FMSO FD-D01 MANUAL.       *
* ALSO SEE FS-D01DX P. K-11, PARA. 38-A.                                  *
***************************************************************************
*                                                                         *
         IF (NIMSC(I).EQ.'5'.OR.NIMSC(I).EQ.'6'.AND.AUTHLV(I).EQ.'8D')
     *   THEN
            R2(I) = 0
*                                                                         *
***************************************************************************
* SEE P. K-11, PARA. 38-B OF THE FMSO FS-D01DX MANUAL FOR THE NEXT 2      *
* LINES.                                                                  *
***************************************************************************
*                                                                         *
         ELSEIF (D(I).EQ.0.0.OR.G(I).EQ.0.) THEN
            R2(I) = IFIX (AMAX1 ((DRTAT(I) + 0.5),0.))
         ELSE
            R2MAX = AMAX1 (R2BAS(I),FLOAT(NRPR(I)))
            R2SL  = 4. * D(I) * SL(I) + DRTAT(I) - 1.
```

```
          IF (LOT(I).NE.0) THEN
             R2MIN = AMIN1 (R2MAX,R2SL,FLOAT(LOT(I)))
          ELSE
             R2MIN = AMIN1 (R2MAX,R2SL)
          ENDIF
          RR2   = AMAX1 (R2MIN,0.)
          R2(I) = IFIX (RR2 + .999)
        ENDIF
   10 CONTINUE
      RETURN
      END
C
/*
//GO.FT10F001 DD *
7H4D 000042754 0 .500 0005 00004637.00 03.92674000 03.92674000
03.92674000 00249.31392000 03.92674000 00000000. 00000007.30 00000462.00
00000000. 00000000 00000001 00000000 V 043.78323000 00000043.70
00000008.00 22 C
7H3A 001779946 0 .500 0002 00005473.00 03.79889000 03.79889000
03.64693440 00327.68970000 03.79413000 00000000. 00000015.70 00000295.00
00000000. 00000000 00000001 00000000 V 040.04028000 00000038.40
00000015.80 22 C
7H3A 001823756 0 .500 0003 00000445.00 03.57152000 03.57152000
03.57152000 00356.06592000 03.57152000 00000000. 00000013.00 00000501.07
00000000. 00000000 00000001 00000000 V 038.57242000 00000038.50
00000013.70 22 C
7H3F 001876676 0 .500 0000 00000683.38 00.03195000 00.03195000
00.02939400 00000.43832000 00.03195000 00000000. 00000000.10 00000500.00
00000000. 00000000 00000001 00000000 V 000.28947000 00000000.20
00000000.10 22 C
7H3C 004940145 0 .500 0000 00022685.79 00.11059000 00.11059000
00.10063690 00004.35817000 00.11059000 00000000. 00000000.00 00008400.00
00000000. 00000000 00000000 00000000 V 000.82280000 00000000.70
00000000.00 22 C
7H4D 008898110 0 .500 0003 00000992.00 03.65600000 03.65600000
03.43664000 00169.91716000 03.65600000 00000000. 00000002.00 00000441.00
00000000. 00000000 00000001 00000000 V 034.22017000 00000032.10
00000002.50 22 C
7H4A 010291741 0 .500 0005 00005425.00 04.29511000 04.29511000
01.93279950 00189.60701000 04.27768000 00000000. 00000002.90 00002957.60
00000000. 00000000 00000001 00000000 V 047.24622000 00000021.20
00000001.70 22 V
7H4B 010292581 0 .500 0003 00000579.21 02.09849000 02.09849000
02.01455040 00081.68222000 02.00876000 00000000. 00000000.80 000000445.0
00000000. 00000000 00000001 00000000 V 019.64189000 00000018.80
00000001.20 22 C
7H3F 010329059 0 .500 0000 00002256.00 00.02488000 00.02488000
00.0216456 000000.32954000 00.02488000 00000000. 00000000.00 00001161.00
00000000. 00000000 00000001 00000000 V 000.19907000 00000000.10
00000000.00 22 C
7H3E 010373691 0 .500 0002 00014434.52 02.52000000 02.52000000
02.39400000 01020.13599000 02.52000000 00000000. 00000010.00 00002500.00
00000000. 00000000 00000001 00000000 V 045.36002000 00000043.00
00000010.00 22 C
7H3A 011126484 0 .500 0000 00498852.96 30.59998000 30.59998000
30.59998000 01414.23926000 30.59998000 00000000. 00000037.90 00045524.50
```

```
00000000. 00000000 00000001 00000008 V 373.93188000 00000373.90
00000043.70 22 C
7G3B 011137212 0 .500 0000 00000638.00 01.25000000 01.25000000
01.08750000 00017.14398000 01.00000000 00000000. 00000001.30 00000238.00
00000000. 00000000 00000000 00000000 V 009.81251000 00000008.50
00000001.30 22 C
/*
//
```

APPENDIX B. HIGH REPAIR SURVIVAL RATE (RSR) COUNTER PROGRAM

```
//DEXA9864 JOB (9864,9999),'M.DEXTER SMC 2334',CLASS=B
//  EXEC FORTVCLG,IMSL=IMSL10
//FORT.SYSIN DD *
*******************************************************************************
* TITLE   :  HIGH REPAIR SURVIVAL RATE (RSR) COUNTER.                         *
* DATE    :  30 JUNE 1989                                                     *
* AUTHOR  :  MARK D. DEXTER                                                   *
* SYSTEM  :  IBM 3033                                                         *
* COMPILER:  FORTRAN LEVEL 77 VERSION 4.1                                     *
*                                                                             *
*******************************************************************************
*                          PROGRAM DESCRIPTION                                *
*******************************************************************************
*                                                                             *
* THIS PROGRAM IS USED TO COUNT THE NUMBER OF 7H COGS ON A CARES DATA         *
* HAVING A REPAIR SURVIVAL RATE (RSR) GREATER THAN OR EQUAL TO A VALUE        *
* SPECIFIED BY THE USER.  LINES 7 AND 8 ARE SET UP AS COMMENTS, BUT BY        *
* ERASING THE 'C' IN COLUMN 1, YOU CAN HAVE THIS PROGRAM PRINT OUT ALL        *
* OF THE RECORDS THAT WERE COUNTED.                                           *
*                                                                             *
* THE VARIABLE I IS WHERE YOU SPECIFY THE RSR PERCENTAGE.                     *
*                                                                             *
*******************************************************************************
*                         VARIABLE DEFINITIONS                                *
*******************************************************************************
*                                                                             *
* CRR   = CARCASS RETURN RATE.  SINCE THE CARES DATA SET DOESN'T HAVE         *
*         THIS VARIABLE, IT IS ESTIMATED BY:                                  *
*                                                                             *
*                      CRR = REGEN / (D * RSR)                                *
*                                                                             *
*         THIS FORMULA IS COURTESY OF PROFESSOR ALAN W. MCMASTERS OF          *
*         THE NAVAL POSTGRADUATE SCHOOL.                                      *
* D     = QUARTERLY DEMAND FORECAST.  COMES FROM THE CARES DATA BASE.         *
* HIRSR = COUNTER TO RECORD THE NUMBER OF RECORDS HAVING A RSR HIGHER         *
*         THAN THE USER SPECIFIED RSR.                                        *
* I     = THE USER SPECIFIED RSR.  THAT IS, IF YOU WANT TO FIND ALL THE       *
*         RECORDS WITH AN RSR >=.90, CHANGE THE FIFTH EXECUTABLE STATE-       *
*         MENT BELOW TO:                                                      *
*                           I = .90                                           *
*                                                                             *
* MARK  = MARK CODE FROM THE CARES DATA SET.                                  *
* NIIN  = NATIONAL ITEM IDENTIFICATION CODE.  THIS IS THE STOCK NUMBER        *
*         FROM THE CARES DATA SET.                                            *
* REGEN = QUARTERLY REGENERATIONS FORECAST.  THIS COMES FROM THE CARES        *
*         DATA SET.                                                           *
* RSR   = REPAIR SURVIVAL RATE.  THIS COMES FROM THE CARES DATA SET.          *
* TAT   = REPAIR TURNAROUND TIME.  THIS COMES FROM THE CARES DATA SET         *
*                                                                             *
```

```
***********************************************************************
*                     VARIABLE DECLARATIONS                           *
***********************************************************************
*                                                                     *
      REAL RSR,TAT,D,REGEN,I,CRR
      CHARACTER MARK(1),NIIN(9)
      INTEGER HIRSR
*                                                                     *
***********************************************************************
*                     INITIALIZE VARIABLES                            *
***********************************************************************
*                                                                     *
      HIRSR = 0
      I = .99
*                                                                     *
***********************************************************************
*                     READ IN THE CARES DATA                          *
***********************************************************************
*                                                                     *
    1 READ(10,5,END=99) MARK,NIIN,RSR,TAT,D,REGEN
    5 FORMAT(4X,A1,9A1,20X,F3.2,F4.2,24X,F10.2,F10.2)
*                                                                     *
***********************************************************************
*                     ESTIMATE THE CRR                                *
***********************************************************************
*                                                                     *
      IF (RSR.NE.0.) THEN
        CRR = REGEN/(D * RSR)
      ELSE
        CRR = 0.
      ENDIF
*                                                                     *
***********************************************************************
* TEST EACH ITEM TO SEE IF THE RSR FROM THE CARES DATA BASE IS GREATER *
* THAN OR EQUAL TO THE USER SPECIFIED VALUE I.                        *
***********************************************************************
*                                                                     *
      IF (RSR.GE.I) THEN
*                                                                     *
***********************************************************************
* YOU CAN PRINT OUT EACH OF THE CARES RECORDS HAVING RSR >=I, BY BLANK- *
* ING OUT THE 'C' IN THE FIRST COLUMN OF THE FOLLOWING WRITE AND FORMAT *
* STATEMENTS.                                                         *
***********************************************************************
*                                                                     *
C   7   WRITE (6,8) MARK,NIIN,RSR,TAT,D,REGEN,CRR
C   8   FORMAT (4X,A1,5X,9A1,3X,F5.2,3X,F4.2,3X,F10.2,3X,F10.2,3X,F10.2)
C   9 WRITE 10
C  10 FORMAT (3X,'MARK',6X,'NIIN',6X,'RSR',4X,'RTAT',5X,'DEMAND',4X,
C    +        'REGENERATIONS',5X,'CRR')
*                                                                     *
***********************************************************************
* INCREMENT THE COUNTER WHEN WE FIND A NSN HAVING RSR >= I.           *
***********************************************************************
*                                                                     *
        HIRSR = HIRSR + 1
```

```
      ENDIF
      GO TO 1
*                                                                              *
********************************************************************************
* PRINT THE NUMBER OF RECORDS HAVING RSR >= I.                                 *
********************************************************************************
*                                                                              *
   99 WRITE (6,100) HIRSR
  100 FORMAT (5X,'NUMBER OF RECORDS WITH RSR >= .98 IS:',I5)
      STOP
      END
/*
//GO.FT10F001 DD DISP=SHR,DSN=MSS.F0935.REP7H
/*
//
```

APPENDIX C. SAMPLE RSR, RTAT, AND D, COUNTER PROGRAM

```
//DEXA9864 JOB (9864,9999),'M.DEXTER SMC 2334',CLASS=B
//  EXEC FORTVCLG,IMSL=IMSL10
//FORT.SYSIN DD *
************************************************************************
* TITLE    :  HIGH RSR, HIGH RSR, AND LOW DEMAND COUNTER PROGRAM       *
* DATE     :  30 JUNE 1989                                             *
* AUTHOR   :  MARK D. DEXTER                                           *
* SYSTEM   :  IBM 3033                                                 *
* COMPILER:   FORTRAN LEVEL 77 VERSION 4.1                             *
*                                                                      *
************************************************************************
*                         PROGRAM DESCRIPTION                          *
************************************************************************
*                                                                      *
* THIS PROGRAM IS USED TO COUNT THE NUMBER OF 7H COGS ON A CARES DATA  *
* HAVING A REPAIR SURVIVAL RATE (RSR) GREATER THAN OR EQUAL TO THAT    *
* SPECIFIED BY THE USER, A LONG REPAIR TURNAROUND (TAT) TIME (TAT > 4  *
* QUARTERS, AND A LOW DEMAND (D < 0.25 PER QUARTER)                    *
*                                                                      *
************************************************************************
*                        VARIABLE DEFINITIONS                          *
************************************************************************
*                                                                      *
* CRR   = CARCASS RETURN RATE.  SINCE THE CARES DATA SET DOESN'T HAVE  *
*         THIS VARIABLE, IT IS ESTIMATED BY:                           *
*                                                                      *
*                        CRR = REGEN / (D * RSR)                       *
*                                                                      *
*         THIS FORMULA IS COURTESY OF PROFESSOR ALAN W. MCMASTERS OF   *
*         THE NAVAL POSTGRADUATE SCHOOL.                               *
* D     = QUARTERLY DEMAND FORECAST.  COMES FROM THE CARES DATA BASE.  *
* HIRSR = COUNTER TO RECORD THE NUMBER OF RECORDS HAVING A HIGH RSR,   *
*         LONG TAT, AND LOW DEMAND.                                    *
* I     = THE USER SPECIFIED RSR.  THAT IS, IF YOU WANT TO FIND ALL THE *
*         RECORDS WITH AN RSR >=.90, CHANGE THE FIFTH EXECUTABLE STATE- *
*         MENT BELOW TO:                                               *
*                            I = .90                                   *
*                                                                      *
* MARK  = MARK CODE FROM THE CARES DATA SET.                           *
* NIIN  = NATIONAL ITEM IDENTIFICATION CODE.  THIS IS THE STOCK NUMBER *
*         FROM THE CARES DATA SET.                                     *
* REGEN = QUARTERLY REGENERATIONS FORECAST.  THIS COMES FROM THE CARES *
*         DATA SET.                                                    *
* RSR   = REPAIR SURVIVAL RATE.  THIS COMES FROM THE CARES DATA SET.   *
* TAT   = REPAIR TURNAROUND TIME.  THIS COMES FROM THE CARES DATA SET  *
*                                                                      *
************************************************************************
*                        VARIABLE DECLARATIONS                         *
************************************************************************
*                                                                      *
      REAL RSR,TAT,D,REGEN,I,CRR
```

```
      CHARACTER MARK(1),NIIN(9)
      INTEGER HITAT
*                                                                      *
************************************************************************
*                        INITIALIZE VARIABLES                          *
************************************************************************
*                                                                      *
      HITAT = 0
      I = .99
*                                                                      *
************************************************************************
*                        READ IN THE CARES DATA                        *
************************************************************************
*                                                                      *
    1 READ(10,5,END=99) MARK,NIIN,RSR,TAT,D,REGEN
    5 FORMAT(4X,A1,9A1,20X,F3.2,F4.2,24X,F10.2,F10.2)
*                                                                      *
************************************************************************
* TEST EACH ITEM TO SEE IF THE RSR FROM THE CARES DATA BASE IS GREATER *
* THAN or equal to THE USER SPECIFIED VALUE I, IF THE TAT IS GREATER   *
* THAN 4 quarters, AND IF THE DEMAND IS LESS THAN 4 per quarter.       *
************************************************************************
*                                                                      *
      IF (TAT.GT.4.AND.RSR.GE.I.AND.D.LT.0.25) THEN
*                                                                      *
************************************************************************
*                        ESTIMATE THE CRR                              *
************************************************************************
*                                                                      *
        IF (RSR.NE.0.0.AND.D.NE.0.0) THEN
          CRR = REGEN/(RSR * D)
        ELSE
          CRR = 0.
        ENDIF
*                                                                      *
************************************************************************
* YOU CAN PRINT OUT EACH OF THE CARES RECORDS HAVING RSR >= I, TAT > 4, *
* AND D < 0.25 BY BLANKING OUT THE 'C' IN THE FIRST COLUMN OF THE FOLL- *
* OWING WRITE AND FORMAT STATEMENTS.                                   *
************************************************************************
*                                                                      *
C   7 WRITE 8
C   8 FORMAT (3X,'MARK',6X,'NIIN',6X,'RSR',4X,'RTAT',5X,'DEMAND',4X,
C       WRITE (6,9) MARK,NIIN,RSR,TAT,D,REGEN,CRR
C   9   FORMAT (3X,A1,3X,9A1,3X,F5.2,3X,F4.2,3X,F10.2,3X,F10.2,3X,F10.2)
C    +         'REGENERATIONS',5X,'CRR')
*                                                                      *
************************************************************************
* INCREMENT THE COUNTER WHEN WE FIND A NSN HAVING RSR >= I, TAT > 4,   *
* AND D < 0.25                                                         *
************************************************************************
*                                                                      *
        HITAT = HITAT + 1
      ENDIF
      GO TO 1
*                                                                      *
```

```
********************************************************************************
* PRINT THE NUMBER OF RECORDS HAVING RSR >=I, TAT > 4, AND D < 0.25            *
********************************************************************************
*                                                                              *
   99 WRITE (6,100) HITAT
  100 FORMAT (5X,'NUMBER OF RECORDS WITH RSR >= .99, RTAT > 4, AND D < .2
     +5 IS: ',I5)
      STOP
      END
/*
//GO.FT10F001 DD DISP=SHR,DSN=MSS.F0935.REP7H
/*
//
```

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